EVALUATION OF CHANNEL SWITCHING THRESHOLD FOR MBMS IN UMTS NETWORKS

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25 June 2008

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Chapter 1

Introduction

The world has witnessed an explosion in the growth of mobile communications in recent years. In fact, year 2002 marked a turning point in the history of telecommunications where the number of mobile subscribers overtook the number of fixed-line subscribers on a global scale, and mobile became the dominant technology for voice communications. Continuous improvement of mobile phones, networks and communication technologies provides users with enhanced existing services and continuous stream of new innovative mobile services. The third generation of mobile technologies (3G) is advancing possibilities again one step further in the near future. Besides already existing services, multimedia streams (e.g. TV on mobile phones) and transmission of broadband data will be offered. Furthermore arbitrary data and applications for smart phones, multimedia clips and streams and many other services will be available for a large group of users. Such services will utilize data transmission or streaming from one server to many users. A system feature required is to provide these transmissions in an efficient way. The Standardizations of Multimedia Broadcast and Multicast Service (MBMS) are dedicated to this task. MBMS is a new unidirectional (downlink only) Point-to-Multipoint service introduced in Universal Mobile Telecommunication System (UMTS) Release 6 specifications in which the same data is transmitted from a single source entity to multiple recipients. The novelty with MBMS architecture is that it enables the efficient usage of radio-network and core-network resources by allowing the network resources to be shared. Power control is one of the most important aspects in MBMS due to the fact that Node B's transmission power is a limited resource and must be shared among all MBMS users in a cell. The main purpose of power control is to minimize the transmitted power, thus avoiding unnecessary high power levels and eliminating inter-cell interference. Consequently, the analysis of transmitted power plays a fundamental role in the planning and optimization process of UMTS radio access networks.

Different transport channels can be used to transmit MBMS data, each one with different power requirements. The benefits of using different transport channels for the transmission of the multicast data over the UTRAN interfaces are investigated in this project. The selection of the most efficient transport channel in terms of power consumption is a key point for the MBMS performance, since a wrong channel selection could result to a significant decrease in the total capacity of the system. The transport channels, in the downlink, currently existing in UMTS which could be used to serve MBMS are the Dedicated Channel (DCH), the Forward Access Channel (FACH) and the High Speed Downlink Shared Channel (HS-DSCH). Each channel has different characteristics in terms of power control. In this work, a power based scheme for the selection of the most efficient channel is investigated. The primary factor which influences the transmission power is the number of the users in the cell. To investigate the appropriate transport channel a model with 19 hexagonal cells has been implemented and interference has always been considered.

The project has the following structure: Chapter 2 is an introduction to Mobile Communications; Chapter 3 serves as an overview to UMTS, from Release '99 to Release 6; Chapter 4 introduces MBMS services including the MBMS channels; Chapter 5 contains detailed descriptions of all the simulations steps, all the conditions, assumptions and configuration values are shown; Chapter 6 presents results of the simulations and their evaluation; finally Chapter 7 summarizes results and conclusions; In Chapter 8 Future Works are proposed.

Chapter 2

Mobile Communications History

2.1 Introduction

From the concept to reuse the same limited radio frequency in different cells to serve an unlimited number of users, the world of Mobile Communications is really grown. During the last two decades the mobile communications systems have changed their scope. In the early mobile generation (1G) only voice was the service required and it used analogue technology. With the introduction of digital technology the second generation (2G) improved the quality of voice service. Instead the lasts mobile generations allow a set of services to reach communications every time and everywhere. For this reason the core networks are evolving from a circuit switched domain to a packet switched domain. The futures evolutions of the third generation (3G) have the aim to allow interactive multimedia services.

The growth of the number of mobile subscribers over the last decades led to a saturation of voice-oriented wireless telephony. As shown in the Figure 2.1, the number is grown from 214 millions of subscribers in 1997 to 1162 millions in 2002 and it is predicted that by 2010 there will be 1700 millions subscribers worldwide. It is now time to find new ways to extend the capability of the network to allow new services according to users' needs. The first step has already been taken by the 2.5G, which gave users access to a data network (e.g. Internet access, MMS – Multimedia Message Service). However, users and applications demanded more communication power. As a response to this demand the 3G has to evolve.

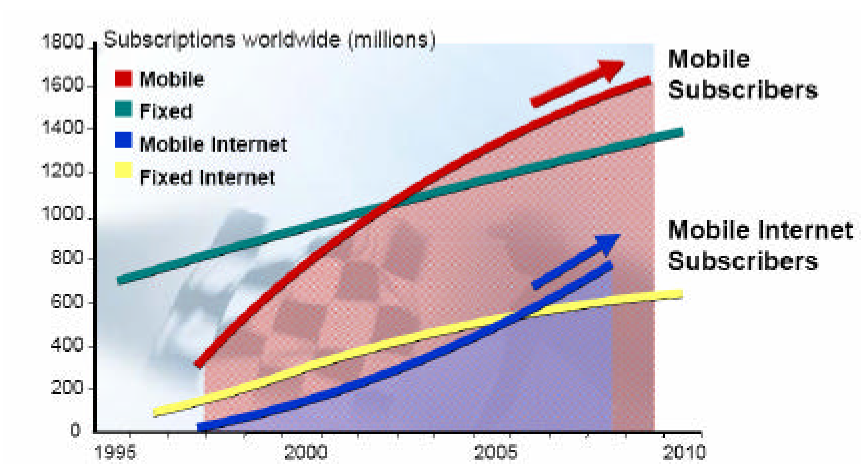

Figure 2.1: Evolution of mobile and fixed subscribers

Recently there has been an evolution of second and third mobile generations which incorporates the features provided by broadband. In addition, next evolutions aim to support mobility and multimedia traffic with quality of service (QoS) guarantee. In fact the challenge that the mobile communications are facing today is how to improve the user experience. Services such as video-conference, fast internet browsing, mobile TV and video streaming are the services that will be supported and consequently terminal will become multimedia device. It is possible that the most important improvement will be the development of new technologies referred to as High Speed Packet Access (HSPA). These technologies will be available as a relatively upgrade to existing UMTS networks and will offer improved bandwidth to the users [1].

This chapter is organized as follows. The first mobile generations (1G to 2.5G) are described in Section 2.2, then the third mobile generation networks (3G) in Section 2.3, the HSPA standardization (3.5G) in Section 2.4 and finally the future mobile generation networks (4G, 3G LTE and SAE, HSPA vs Mobile WiMAX: why HSPA) are presented in Section 2.5.

2.2 The first and second mobile generations (1G to 5.5G)

2.2.1 1G

The first generation mobile standards were based on analogue technology. The mobile market in this time was fragmented, where a variety of standards were developed and used in different countries. The Nordic Mobile Telephone (NMT) is one of the earliest 1G-standards. NMT was developed jointly in Denmark, Finland, Iceland, Norway and Sweden. NMT operated originally in the 450 MHz band and later also in the 900 MHz (NMT-900). In Europe, Total Access Communications Systems (TACS) was introduced with 1000 channels and a signalling data rate of 8 Kbps. In the US the Advanced Mobile Phone System (AMPS) standard developed by the Bell labs was in use in 1883. Because of the level of fragmentation of the market, efficient harmonization and interoperability was either not possible or at best a very complicated process. Hence one of the requirements for the next generation mobile was the use of common standards and the creation of a single market for mobile. Another main requirement for the new standards was a more optimal utilization of frequency resources. This requirement has been fulfilled by selecting digital technology as the foundation for all the 2G standards and beyond. The most popular 2G standard is the Global System for Mobile Communications (GSM).

2.2.2 GSM (2G)

The standardisation work of GSM-based systems has its roots in the 1980s, when a standardization body 'Groupe Special Mobile' (GSM)[1] was created within the Conférénce Européenne des Postes et Telecommunications (CEPT), whose task was to develop a unique digital radio communication system for Europe, at 900 MHz. Since the early days of GSM development, the system has experienced extensive modifications in several steps to satisfy the increasing demand from the operators and cellular users. The main part of the basic GSM system development during the last decade until spring 2000 has been conducted in the European Telecommunications Standards Institute (ETSI) Special Mobile Group (SMG) [8].

The need for continuous development of the GSM specifications was anticipated at the beginning of the specification work, which was, as a consequence, split into two phases. This phased approach was defined to make sure that specifications supported a consistent set of

1 The original GSM acronym is 'Groupe Special Mobile'. This changed afterwards to Global System for Mobile communication, which is the current official acronym.

features and services for multi-vendor operation of the GSM products, both on the terminal and the network sides.
The GSM Phase 1 work included most common services to enable as fast as possible deployment of GSM in operating networks still providing a clear technological advance compared with existing analogue networks. The main features in Phase 1 include support for basic telephony, emergency calls, 300 to 9600 kbps data service, ciphering and authentication as well as supplementary services like call forwarding. Also, short message service (SMS) was also included at this early phase of the specification work, although its commercial success came much later.
While the GSM Phase 1 networks was being built, GSM Phase 2 has been specified in ETSI SMG. The GSM Phase 2 specifications were frozen in October 1995, and they included a mechanism for cross-phase compatibility and error handling to enable evolution of the specifications. Many technical improvements were also introduced and included several new supplementary services like line identification services, call waiting, call hold, advice of charge and multi-party call. In the speech area, a half-rate channel mode codec was introduced to complement the already specified speech codec for GSM full-rate channel mode.

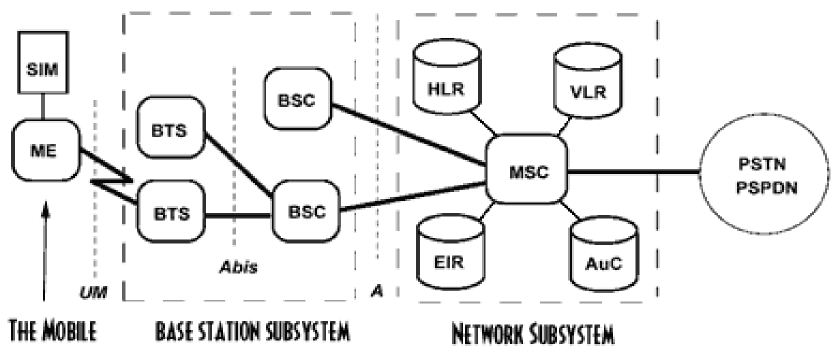

Figure 2.2 : GSM Architecture

Follow there is a brief overview of GSM architecture that it is shown in Figure 2.2.
The area covered by a GSM network provider is divided into a number of cells. Each cell has a unique identity (Cell Identifier or CI), and it has a subset of the total radio frequencies available to the network provider. Frequencies assigned to a particular cell 'i' can be reused in other cells that are at a minimum distance from the cell 'i'. At the center of each cell, a Base Station Transceiver (BTS) provides mobile subscribers with radio channels for both signaling and user payload traffic in the cell area. More BTSs are connected to one Base Station Controller (BSC), which provides the required intelligence for signal processing. The pair BTS and BSC when combined together is referred-to as the Base Station Subsystem (BSS). BSCs are connected together through a Mobile Switching Center (MSC), which performs the functions of switching, routing path search, signal routing and service feature processing. The MSC has also to consider the allocation and administration of radio resources and the mobility of the subscribers. A Public Land Mobile Network (PLMN) usually has several MSCs with each being responsible for a Mobile Switching Region. Connection to a fixed network (PSTN, ISDN or other) is routed through a *Gateway MSC*

(GMSC), which is a dedicated MSC to route traffic through fixed networks. There are four important databases that are essential to the operation of a GSM network:

- The Home Location Register (HLR), which is the home registry for all the subscribers. The HLR holds all the permanent data of the subscribers of that "home" network and usually there is one central HLR per PLMN.
- The Visiting Location Register (VLR) holds subscribers data in a certain MSC Region.
- The Authentication Center (AUC) database store the confidential keys serving for user authentication.
- The Equipment Identity Register (EIR) store the International Mobile Equipment Identifier (IMEI) of all mobile equipments.

GSM uses both Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). Actually there are two frequency bands of 25 MHz: 890-915 MHz for the uplink and 935-960 MHz for the downlink. Each of these bands is further divided into 124 single carrier channels of 200 kHz and remains a guard band of 200 kHz between the uplink downlink bands. Each of the pairs of 124 single carrier channels is then divided using a TDMA into 8 timeslots and allows eight simultaneous calls on the same frequency. The FDMA and TDMA structure of GSM channels is shown in Figure 2.3

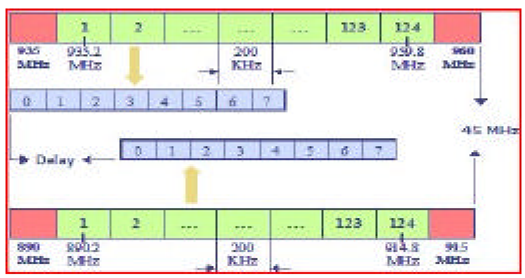

Figure 2.3 : GSM FDMA TDMA structure

This scheme allows large numbers of users to access one radio frequency by allocating time slots to multiple voice or data calls. TDMA divides data transmission, such as a phone conversation, into fragments and transmits each fragment in a short burst, assigning each fragment in a time slot. Of course, the caller does not detect this fragmentation.

The first-phase of GSM specifications provided only basic transmission capabilities for the support of data services, with the maximum data rate in these early networks being limited to 9.6 kbps on one timeslot. High-Speed Circuit-Switched Data (HSCSD) specified in Rel'96 was the first GSM Phase 2+ work item that clearly increased the achievable data rates in the GSM system. The maximum radio interface bit rate of an HSCSD configuration is 115.2 kbps. In practice, the maximum data rate is limited to 64 kbps by A-interface[2] limitations. The main benefit of the HSCSD feature compared to other data enhancements introduced later is that it is an inexpensive way to implement higher data rates in GSM networks by relatively small incremental modifications needed for the network equipment. In HSCSD, a new functionality is introduced at the network and terminals to provide the functions of

2 The A -interface is the interface in GSM network architecture between the BSS and an MSC. The interface supports standard 64Kbps channels for signalling and traffic.

combining and splitting the user data into separate n data streams, which will then be transferred via n channels at the radio interface, where n = 1, 2, 3, . . ., 8. Once split, the data streams shall be carried by the n traffic channels, called HSCSD channels.

2.2.3 GPRS (2.5G)

Soon after the first GSM networks became operational in the early 1990s and the use of the GSM data services started, it became evident that the circuit-switched bearer services were not particularly well suited for certain types of applications with a bursty nature [8]. The circuit-switched connection has a long access time to the network, and the call charging is based on the connection time. In packet-switched networks, the connections do not reserve resources permanently, but make use of the common pool, which is highly efficient, in particular, for applications with a bursty nature. The GPRS system will have a very short access time to the network and the call charging could solely be based on an amount of transmitted data. The GPRS system brings the packet-switched bearer services to the existing GSM system. In the GPRS network, uplink and downlink channels are reserved separately, making it possible to have Mobile Stations (MSs) with various uplink and downlink capabilities. The resource allocation in the GPRS network is dynamic and dependent on demand and resource availability. Packets can also be sent on idle time between speech calls. With the GPRS system, it is possible to communicate point-to-point (P-t-P) or point-to-multipoint (P-t-M); it also supports the SMS and anonymous access to the network. The theoretical maximum throughput in the GPRS system is 160 kbps per MS using all eight channels without error correction.
In Figure 2.4 the GPRS architecture is shown.

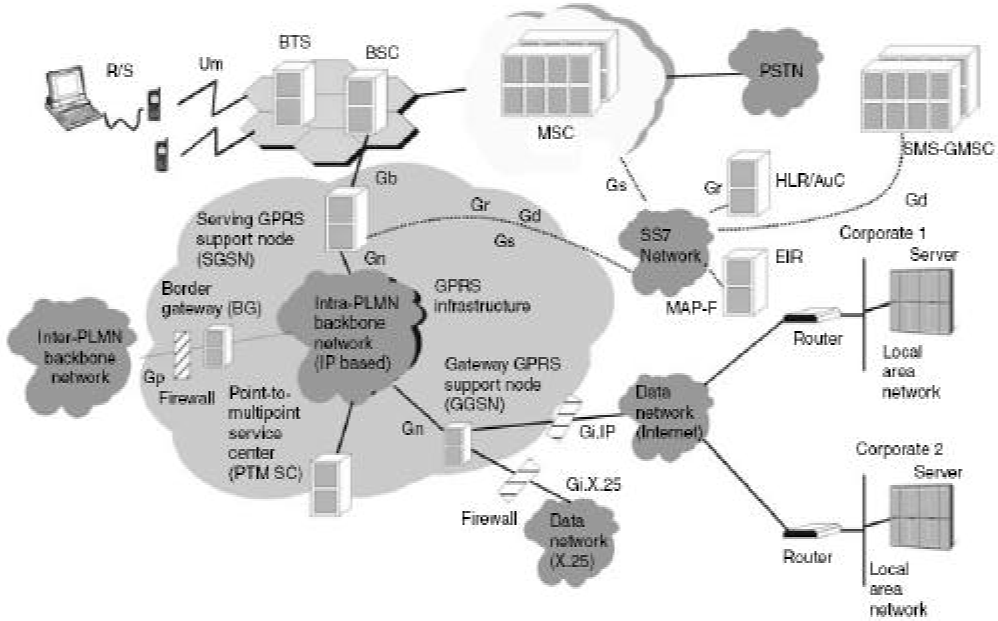

Figure 2.4 : GPRS Architecture

GPRS brings few new network elements to the GSM network. The most important are the serving GPRS Support Node (SGSN) and the gateway GPRS Support Node (GGSN).

The SGSN is a component of the GPRS network, which handles, e.g. the mobility management and authentication and has register function. The SGSN is connected to the BSC and is the service access point to the GPRS network for the GPRS MS. The SGSN handles the authentication of GPRS mobiles, and when the authentication is successful, the SGSN handles the registration of an MS to the GPRS network and takes care of its mobility management.

The GGSN is connected to the external networks. From the external networks' point of view, the GGSN is a router to a sub-network, because the GGSN 'hides' the GPRS infrastructure from the external networks. When the GGSN receives data addressed to a specific user, it checks if the address is active. If it is, the GGSN forwards the data to the SGSN serving the MS, but if the address is inactive, the data are discarded. The mobile-originated packets are routed to the right network by the GGSN.

The BSS allocates resources to a user upon activity (when data are sent or received) and releases them immediately thereafter.

The HLR is upgraded and contains GPRS subscription data. For roaming MSs, HLR is in a different PLMN than the current SGSN. All MSs use their HLR in Home Public Land Mobile Network (HPLMN). The HLR is enhanced with GPRS subscriber information.

Another important new element is the Point-to-Multipoint Service Centre (PTM-SC), which is dedicated to the P-t-M services in the GPRS network. Another new network element is the border gateway (BG), which is mainly needed for security reasons and is situated on the connection to the inter-PLMN backbone network. The inter-PLMN and intra-PLMN backbone networks are also new elements, both Internet Protocol-based (IP-based) networks.

2.2.4 EDGE

Enhanced Data Rates for GSM Evolution (EDGE) is a major enhancement to the GSM data rates. GSM networks have already offered advanced data services, like circuit-switched 9.6-kbps data service and High-Speed Circuit-Switched Data (HSCSD) with multislot capability. HSCSD and GPRS are both major improvements, increasing the available data rates from 9.6 kbps up to 64 kbps (HSCSD) and 160 kbps (GPRS). EDGE is specified in a way that will enhance the throughput per timeslot for both HSCSD and GPRS. The enhancement of HSCSD is called Enhanced Circuit-Switched Data (ECSD), whereas the enhancement of GPRS is called Enhanced General Packet Radio Service (EGPRS). In ECSD, the maximum data rate will not increase from 64 kbps because of the restrictions in the A-interface, but the data rate per timeslot is triple. Similarly, in EGPRS, the data rate per timeslot is triple and the peak throughput, with all eight timeslots in the radio interface, can reach 473 kbps. The 'enhancement' behind tripling the data rates is the introduction of the 8-PSK (octagonal phase shift keying, it is shown in Figure 2.5) modulation in addition to the existing Gaussian minimum shift keying. An 8-PSK signal is able to carry 3 bits per modulated symbol over the radio path, while a GMSK signal carries only 1 bit per symbol [8].

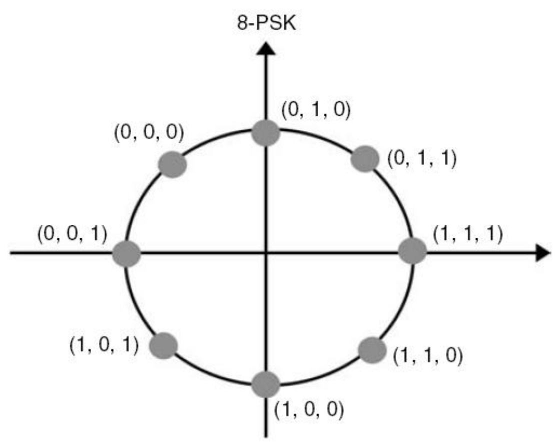

Figure 2.5 : 8-PSK

2.2.5 GERAN Standardisation in 3GPP

In summer 2000, the specification work of GSM radio was moved from ETSI SMG2 to 3GPP, which is a project responsible of the UMTS standards based on the evolved GSM core network. The moving of the specifications was motivated by both the need for improved working procedures and technical development closer to 3GPP. The core network part of the GSM specifications was transferred to 3GPP by the time the project work was initiated, and the arrangement of standardising the GSM network and radio access parts in two different standardisation bodies made it too cumbersome to work effectively. More importantly, activities aimed at closer integration of GSM/EDGE radio and WCDMA technologies had led to a decision to adopt the 3GPP-specific Iu interface for GERAN. Thereby, this integration achieves a true multi-radio UMTS standard, which is made up of two radio technologies, WCDMA and GSM/EDGE, that can be effectively and seamlessly integrated in order to maximise the efficiency and the quality of service provided to the end users with the introduction of the coming 3G multimedia services**.**

2.3 The third generation mobile networks (3G)

All 2G wireless systems enabled voice traffic to go wireless; the number of mobile phones exceeds the number of fixed phone and the mobile phone penetration exceeds 80% in countries with the most advanced wireless markets. The data capabilities of second generation systems are limited. GSM includes short message service (SMS), enabling text messages of up to 160 characters to be sent, received and viewed on the handset. Most 2G systems also support some data over their voice paths, but at slow speeds usually 9.6 Kb/s or 14.4 Kb/s. So in the world of 2G, voice remains king while data is already dominant in wired communications. Also, fixed or wireless, all are affected by the rapid growth of the Internet. An issue for 3G wireless is that users will want to roam worldwide and keep connected. Today, GSM leads in global roaming. Because of the pervasiveness of GSM, users can get comprehensive coverage in Europe, parts of Asia and some U.S. coverage. A key goal of 3G is to make this roaming capacity universal [7].

2.3.1 UMTS

Third generation systems are designed for multimedia communications such as high quality images and videos, high data rate access to information and services on public and private networks. Works to develop third generation systems started when the World Administrative Radio Conference (WARC) of the International Telecommunication Union (ITU), at its 1992 meeting, identified the frequencies around 2 GHz that were available for the use by future third generation mobile systems. International Mobile Telecommunications -2000 (IMT-2000) is the official international telecommunication union name for 3G and is an initiative intended to provide wireless access to global telecommunication infrastructure through both satellite and terrestrial systems, serving fixed and mobile phone users via both public and private telephone networks [5].

This third generation mobile systems include the Universal Mobile Telecommunication System (UMTS) standardized by 3G Partnership Project (3GPP) in Europe while CMDA2000 is in USA. UMTS uses the radio technology called W-CDMA (Wideband Code Division Multiple Access). W-CDMA is characterized by the use of a wider band than CDMA. W-CDMA has additional advantages of high transfer rate, and increases system capacity and communication quality by statistical multiplexing. The W-CDMA solution brings advanced capabilities that enable new services. Such capabilities are:

- high bit rate theoretically up to 2 Mbps in 3GPP Release '99, beyond 10 Mbps in 3GPP Release 5; practical bit rate are up to 384 Kbps initially and beyond 2 Mbps with Release 5;

- low delay with packet round trip times below 200 ms;
- seamless mobility also for packet data applications;
- QoS differentiation for high efficiency of service delivery;
- interworking with existing GSM/GPRS networks.

These advanced radio capabilities, combined with IP multimedia Sub-System (IMS), allow fast introduction of new services.

The introduction of UMTS has required the installation of a completely new radio sub-system, UMTS Radio Access Network (UTRAN). The first version of UMTS increased the data bit rate handled on the radio interface and multimedia services such video-calls, was proposed to subscribers. Variable bit rate on radio interface was another advantage offered by UMTS compared with 2G and 2.5G. The main components of a UMTS network are:

- User Equipment (UE), which includes the Mobile Equipment (ME), which is a radio terminal handling the communications on radio interface, and the UMTS Subscriber Identity Module (USIM), which is a smart card including user data;
- Radio Network Controller (RNC), which controls radio resource within its related Node B;
- Node B, which converts the data flows through the radio interfaces.
- Core Network, which allows all the network protocols.

The UMTS architecture is shown in Figure 2.6, it includes some node of GSM network.

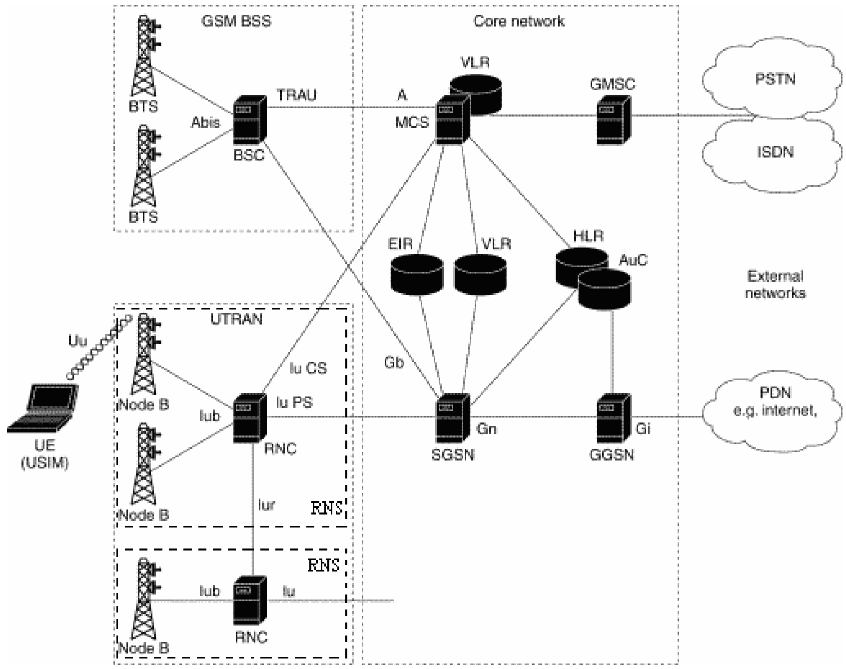

Figure 2.6: UMTS Architecture

As shown in Figure 2.6, UTRAN is divided into a Radio Network Subsystems (RNSs). One RNS consists of one or more Node B (radio element) and only one RNC, which can control more than one Node B.

UMTS allows QoS differentiation, in fact when the network load gets higher, it becomes important to prioritise the different services to their requirements. UMTS uses four traffic classes and the main distinguishing factor is the delay sensitive of the traffic: the conversational class is a very delay sensitive traffic while background class is the most insensitive. The guaranteed bit rate defines the minimum bearer bit rate that UTRAN must provide. Actually UMTS provides this by four kinds of bearer services. Each bearer service ensures a QoS for the relative traffic class [5].

In the Release 4 the UMTS core network level has been evolved, the Mobile Switching Centre (MSC)/Visitor Location Register[3] (VLR) becomes MSC servers and Media Gateway (MG). The MSC server manages the communications and user mobility and MG is responsible for the routing functions. The MSC server can manage many MG, which allows a better separation between control functions and routing functions.

The Release 5 of UMTS specifications was a crucial step towards the development and implementation of services in the mobile environment. In fact it standardized the High Speed Downlink Packet Access (HDSPA) technique which allows a significant increase of the bit rates and it becomes possible to reach theoretical 14 Mbit/s on the downlink channel.

Release 6 introduced further enhancements to UMTS including High Speed Uplink Packet Access (HSUPA) and Multicast Broadcast Multimedia Systems (MBMS). HSDPA and HSUPA make together the High Speed Packet Access (HSPA) system. UMTS Release 6

3 Circuit part of the cellular network.

takes a radical approach to the introduction of conversational and real time interactive multimedia services over an end to end IP transport provider by an enhanced general packet radio service in the packet switched domain. It specifies a voice and multimedia services network called Internet protocol Multimedia Subsystem Core Network (IMS CN). The IMS CN comprises all CN elements to allow IP multimedia applications over IP multimedia sessions. It relies on a managed GPRS and core IP network that is enabled to provide the quality of service needed for voice and multimedia services [6]. The architecture of UMTS Release 6 is shown in Figure 2.7.

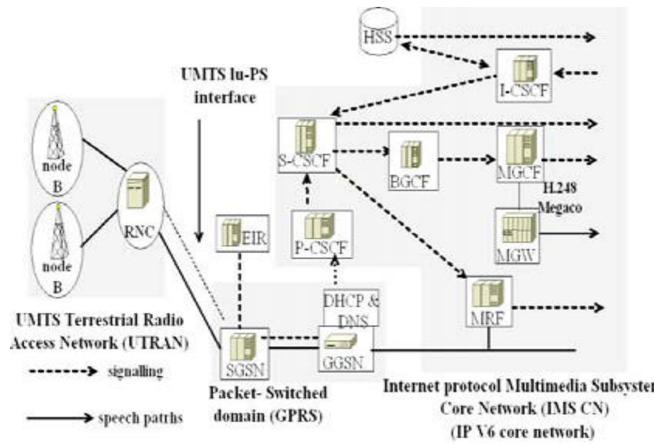

Figure 2.7: UMTS Release 6 Architecture

In Release 7 evolution of HSPA has been investigated.

2.3.2 HSPA standardization (3.5G)

High Speed Packet Access (HSPA) system is a generic term adopted by the UMTS Forum to refer to both improvements of HSDPA and HSUPA standards. Actually High Speed Downlink Packet Access (HSDPA) was standardized as part of 3GPP Release 5 with the first specification version in March 2002 while High-Speed Uplink Packet Access (HSUPA) was introduced in 3GPP Release 6 with the first specification version in December 2004. HSDPA enables data transmission of up to 14.4 Mbit/s per user. The data rate evolution is shown in Figure 2.8. Both HSDPA and HSUPA can be implemented in the standard 5 MHz carrier of UMTS networks and can coexist with the first generation of UMTS networks based on the 3GPP Release 99 standard. HSPA standards refer uniquely to the access network, there is no change of the core network outside of the capacity increases that will be required to handle the expected increase in traffic generated by HSPA [2].

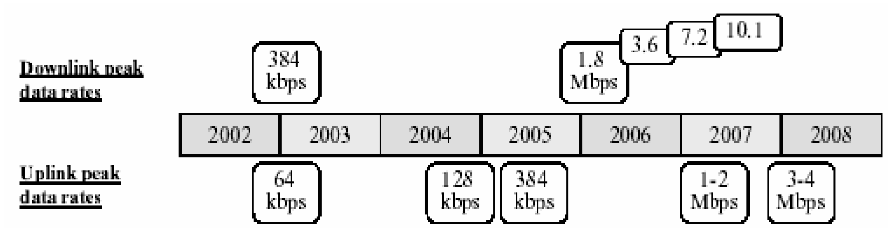

Figure 2.8: Data Rate Evolution

The HSDPA peak data rate available in the terminals was initially 1.8Mbps and it has been increased to 3.6 and 7.2 Mbps during 2006 and 2007. The HSUPA peak data rate in the initial phase was 384 Kbit/s, it has been increased to 2–3 Mbps and now it has a theoretical 5.8 Mbps [7].

HSPA has been commercially deployed by over 100 operators in more than 50 countries. It is expected that in 2010, when the number of wireless broadband connections are estimated to over 600 million, HSPA will be the technology behind over 70 per cent of mobile broadband connection.

HSDPA introduced a number of new technical capabilities to the radio access network, which when combined offer a significant improvement for both end users and operators. These capabilities are:

- a new common High Speed Downlink Shared Channel (HS-DSCH) which can be simultaneously shared by multiple users;
- the use of a shorter Transmission Time Interval (TTI) of 2 ms, which enables higher speed transmission in the physical layer;
- the use of fast scheduling;
- the use of Adaptive Modulation and Coding (AMC);
- the use of fast retransmission based on fast Hybrid Automatic Response reQuest (HARQ) techniques.

Similarly to HSDPA in the downlink, HSUPA defines a new radio interface for the uplink communication. The overall goal is to improve the coverage and throughput as well as to reduce the delay of the uplink dedicated transport channels. The technical capabilities introduced with HSUPA are:

- a new dedicated uplink channel;
- introduction of HARQ;
- fast Node B scheduling.

How often or how many users are able to achieve the HSPA rate obviously depends on the network and radio conditions. The performance of the radio system defines how many smoothly applications can be used over the radio network. The key parameters that define application performance include data rate and network latency. There are applications that are happy with low bit rates of a few tens of kbps but require very low delay, like Voice Over

IP (VoIP) and real time action games. On the other hand, the download time of a large file is only defined by the maximum data rate, and latency does not play any role.

WCDMA enables peak data rates of 384 kbps with latency 100–200 ms, which makes Internet access close to low-end digital subscriber line (DSL) connections and provides good performance for most low-delay Internet Protocol (IP) applications as well [3].

HSPA pushes the data rates up to 3Mbps and reduces network latency to below 100 ms, in this way the end user experienced performance is similar to the fixed line DSL connections. Radio capability evolution from GPRS to HSPA is illustrated in Figure 2.9.

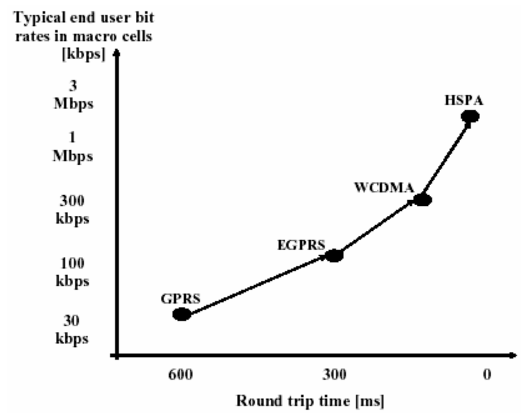

Figure 2.9 : Radio capability evolution

Although HSPA as defined in Release 6 is a significant enhancement to the packet-data functionality in WCDMA, the performance is further enhanced in Release 7.

In Release 7 there has also been introduced the Multiple Input Multiple Output (MIMO) functionality. MIMO is introduced to increase the peak data rate through multi-stream transmission. Strictly speaking, MIMO, in its general interpretation denotes the use of multiple antennas at both transmitter and receiver. This can be used to obtain a diversity gain and thereby increase the carrier-to-interference ratio at the receiver. However, the term is commonly used to denote the transmission of multiple layers or multiple streams as a mean to increase the data rate in a given channel. Hence, MIMO, or spatial multiplexing, should mainly be seen as a tool to improve the end-user throughput. However, to achieve these data rates, a correspondingly high carrier-to-interference ratio at the receiver is required. Therefore spatial multiplexing is manly applicable in smaller cells or close to the base station. In situation where a sufficient high carrier-to-interference ratio cannot be achieved, the multiple receiver antennas, which a MIMO-capable UE is equipped with, can be used for receive diversity[4] also for a single-stream transmission. Hence, a MIMO-capable UE will offer higher cell-edge data rates also in large cells, compared to a corresponding single-antenna UE [7].

In Release 7 and 8 is defined HSPA+, which allows the introduction of a simpler, 'flat', IP-oriented network architecture while bypassing many of the legacy equipment requirements of UMTS/HSPA. Peak data rates with HSPA+ are 28 Mbit/s on the downlink and 11.5 Mbit/s

4 Through Diversity is possible to receive the same signal form more than one cell.

on the uplink using 2x2 MIMO antennas techniques and 16QAM. However, HSPA+ can further boost data rate up to 42 Mbit/s on the downlink and 23 Mbit/s on the uplink using 2x2 MIMO and 64QAM, a combination that is part of Release 8.

2.4 The future mobile generation networks (4G, 3G LTE and SAE)

2.4.1 3G LTE and SAE

The cellular technologies specified by 3GPP are the most widely deployed in the world, with the number of users exceeding 2 billion in 2006. The latest step being studied and developed in 3GPP is an evolution of 3G and an evolved radio access referred to as the Long-Term Evolution (LTE). To support the new packet-data capabilities provided by the LTE radio interfaces, an evolved core network has been developed. The work on specifying the core network is commonly known as System Architecture Evolution (SAE).

To obtain these aims the requirements for LTE are divided into several different areas:

- capabilities, which targets are 300 Mbit/s for downlink and 75 Mbit/s for uplink;
- system performance, which includes throughput, mobility and coverage;
- architecture, which should be packet based, although real-time and conversation class traffic should be supported;
- radio resource management, which support the end-to-end QoS;
- general aspect, which includes the cost aspect.

The SAE system should be able to operate with more than the LTE radio access network and there should be mobility functions allowing a mobile terminal to move between the different radio access systems. In fact, the requirements do not limit the mobility between radio access network. Roaming is a very strong requirement for SAE, including inbound and outbound roaming to other SAE networks. Furthermore, interworking with legacy packet-switched and circuit-switched services is a requirement. Of course, the SAE requirements require that the traditional services such voice, video, messaging and data file exchange should be supported. Several charging models, including calling party pays, flat rate, and charging based on QoS is required to be supported in SAE.

2.4.2 4G

The new 4G framework will try to accomplish new levels of user experience and multi-service capacity by also integrating all the mobile technologies that exist (e.g. GSM - Global System for Mobile Communications, GPRS - General Packet Radio Service, IMT-2000 - International Mobile Communications, Wi-Fi - Wireless Fidelity, Bluetooth). This concept is commonly referred as heterogeneous network.

All the different approaches, agree that the main objectives of 4G networks can be stated in the following properties:

- ubiquity;
- multi-service platform;
- low bit cost.

These properties are explained below.

Ubiquity means that this new mobile networks must be available to the user, any time, anywhere. To obtain this objective services and technologies must be standardized in a worldwide scale. Furthermore the services to be implemented should be available not only to humans as have been the rule in previous systems, but also to everything that needs to communicate. In this new world we can find transmitters in our phone to enable voice and data communications (e.g. high bandwidth Internet access, multimedia transmissions), in our wrist, to monitor our vital signs, in the packages that we send, so that we always know their location, in cars, to always have their location and receive alerts about an accident, in remote monitor/control devices, in animals to track their state or location, etc.

A multi-service platform is an essential property of the new mobile generation, not only because it is the main reason for user transition, but also because it will give telecommunication operators access to new levels of traffic. Voice will loose its weight in the users' bill with the raise of more and more data services.

Low-bit cost is an essential requirement in a scenario where high volumes of data are being transmitted over the mobile network.

To achieve the proposed goals, a very flexible network that aggregates various radio access technologies, must be created. This heterogeneous network must provide high bandwidth, from 50-100 Mbps for high mobility users, to 1Gbps for low mobility users. Technologies that permit an efficient delivery system over the different wireless technologies should be available. It is also necessary a QoS framework that enables fair and efficient medium sharing among users with different QoS requirements. The core of this network should be based in Internet Protocol version 6 – IPv6. The network should also offer sufficient reliability by implementing a fault-tolerant architecture and failure recovering protocols.

Terminal mobility will be a key factor of 4G networks. Terminals must be able to provide wireless services anytime, everywhere. This implies that roaming between different networks must be automatic and transparent to the user.

2.4.3 HSPA vs Mobile WiMAX: why HSPA

HSPA and Mobile WiMAX are designed for high-speed packet data services and share many similar technology enablers. However, there are differences in the uplink rate, architecture and coverage they provide.

Theoretically, it is possible to calculate the upper limits of performance that HSPA and Mobile WiMAX can achieve. The theoretical rates performance for each technology are summarized in Figure 2.10.

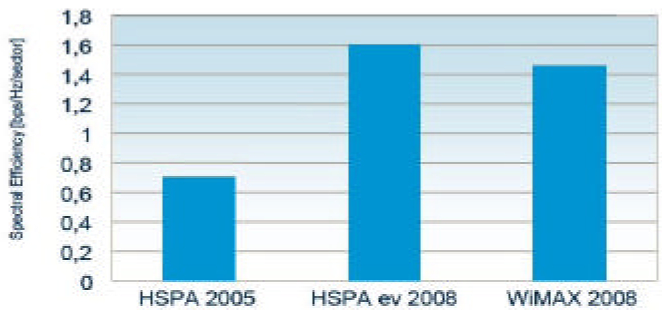

Figure 2.10 : HSPA Mobile WiMAX Rate Performance

HSPA is a Frequency Division Duplex (FDD) technology, in which the uplink and downlink are in separate frequency channels. Mobile WiMAX is a Time Division Duplex (TDD) technology, in which there is just one frequency channel that is shared between the uplink and downlink.

Both technologies offer similar peak data rates, spectral efficiency and network complexity. HSPA is a proven mobile broadband technology that is already deployed in over 100 commercial networks. It is built on firm foundation of the 3GPP family, offering the carrier-grade voice services users expect and the broadband speeds they desire. HSPA can be built out the existing radio network sites and is a software upgrade of the installed WCDMA networks.

By 2010, when the number of wireless broadband connections are estimated to more than 600 million, HSPA will be the technology behind over 70 per cent of mobile broadband connections, as shown in Figure 2.11 [9].

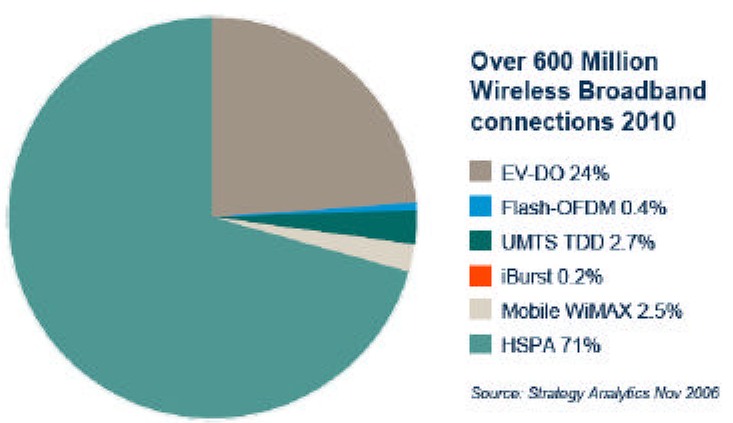

Figure 2.11 : market share of mobile technologies

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Chapter 3

UMTS from Release '99 to HSPA

3.1 Introduction

The basic idea of the UMTS network development is to separate the core and access networks. UMTS network is designed from the beginning for flexible delivery of any type of service and it uses WCDMA radio access solution to bring advanced capabilities. The services are divided into person-to-person services, content-to-person services and business connectivity. Person-to-person refers to a peer-to-peer or intermediate server based connection between two persons or a group of persons. Content-to-person services are characterised by the access to information or download of content. Business connectivity refers to the laptop access to internet using WCDMA as the radio modem [1]. UMTS allows asymmetric services and uses Bearer Service. Bearer Service is a transport service which includes all the necessary characteristics to guarantee QoS, i.e. signalling and user data delivery.

This chapter is organized as follows. UMTS Architecture is described in Section 3.2, then WCDMA in Section 3.3, UMTS Channels in Section 3.4, Radio Interface Protocols in Section 3.5, UMTS Evolution in Section 3.6, and finally HSPA in Section 3.7.

3.2 UMTS Architecture

The UMTS system consists of a number of logical network elements that each has a defined functionality. Functionally the network elements are grouped into the Radio Access Network that handles all radio-related functionality, and the Core Network, which is responsible for switching and routing calls and data connections to external networks. To complete the system, the User Equipment (UE) that interfaces with the user and the radio interface is specified. From a specification and standardization point of view, both UE and UMTS Terrestrial Radio Access Network (UTRAN) consist of completely new protocols. On the contrary, the definition of Core Network (CN) is inherited from GSM. This gives the system with new radio technology a global base of known CN technology that accelerates and facilitates its introduction, and enables such competitive advantages as global roaming

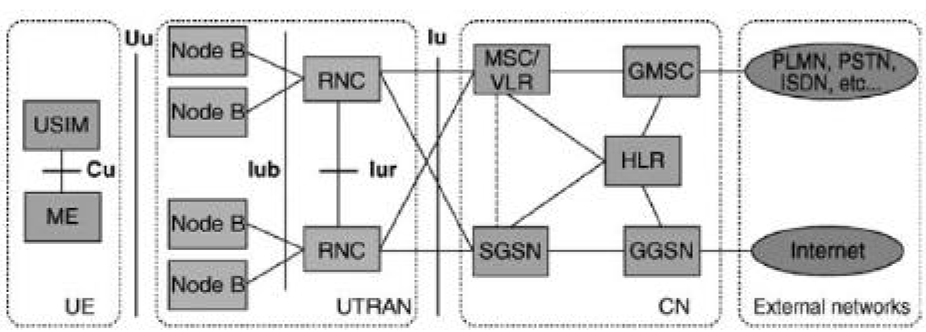

Figure 3.1 : UMTS architecture

[1][2]. The UMTS architecture is shown in Figure 3.1.

The main elements of the GSM CN are:

- HLR (Home Location Register) is a database located in the CN that stores the master copy of the user's service profile. The service profile consists of, for example, information on allowed services, forbidden roaming areas, and supplementary service information such as status of call forwarding and the call forwarding number. It is created when a new user subscribes to the system, and remains stored as long as the subscription is active. For the purpose of routing incoming transactions to the UE (e.g. calls or short messages), the HLR also stores the UE location on the level of MSC/VLR and/or SGSN, i.e. on the level of the serving system.
- MSC/VLR (Mobile Services Switching Centre/Visitor Location Register) are the switch (MSC) and database (VLR) that serve the UE in its current location for Circuit Switched (CS) services.
- GMSC (Gateway MSC) is the switch at the point where UMTS PLMN is connected to external CS networks. All incoming and outgoing CS connections go through GMSC.
- SGSN (Serving GPRS Support Node) functionality is similar to that of MSC/VLR but is typically used for Packet Switched (PS) services.
- GGSN (Gateway GPRS Support Node) functionality is close to that of GMSC but is in relation to PS services.

The external networks can be divided into two groups:

- CS networks. They provide circuit-switched connections, like the existing telephony service.
- PS networks. They provide connections for packet data services. The Internet is one example of a PS network.

The following main open interfaces are specified:

- Cu interface. This is the electrical interface between the USIM smartcard and the ME. The interface follows a standard format for smartcard.
- Uu interface. This is the WCDMA radio interface through which the UE accesses the fixed part of the system, and is therefore probably the most important open interface in UMTS.
- Iu interface which connects UTRAN to the CN.
- Iur interface which connects RNC to each other.
- Iub interface which connects a Node B and an RNC.

UTRAN consists of one or more Radio Network Sub-systems (RNS). An RNS consists of one Radio Network Controller (RNC) and one or more Node Bs. RNCs may be connected to each other via an Iur interface. RNCs and Node Bs are connected with an Iub interface. The Node B converts the data flow between the Iub and Uu interfaces. It also participates in radio resource management. The Radio Network Controller (RNC) owns and controls the radio resources in its domain (the Node Bs connected to it). Main functions of the Node B are to perform channel coding and interleaving, rate adaptation and spreading. It also performs some basic Radio Resource Management operations such as the power control.

UTRAN has the following functions:

- User Data Delivery. Through Iu and Uu interfaces;
- Systems access control. It allows user to connect and to use UMTS services;
- Radio channel coding and decoding;
- Mobility Functions;
- Radio resources management.

By systems access control, UTRAN allows access control, i.e. accepts or refuses new users to not overload the network on preserving low interference, and congestion control.

The mobility functions are handover, which depends on power level measurements to preserve the QoS, and user position. Node Bs and RNCs can handle the handover. Actually the handover between base stations belonging to the same Node B is managed only by the Node B. Instead the handover between base station belonging to different Node B but to the same RNC is managed by RNC through Iub interface. Finally the handover between base station belonging to different Node B and different RNCs is managed by RNCs by Iur interface.

The radio resources management functions are the following:

- Radio resources configuration, which manages the radio resources on configuring the common transport channels;
- Radio channels monitoring, which generates channel characteristics estimations;
- Connection establishment and release;
- Power control;
- Channel coding and decoding.

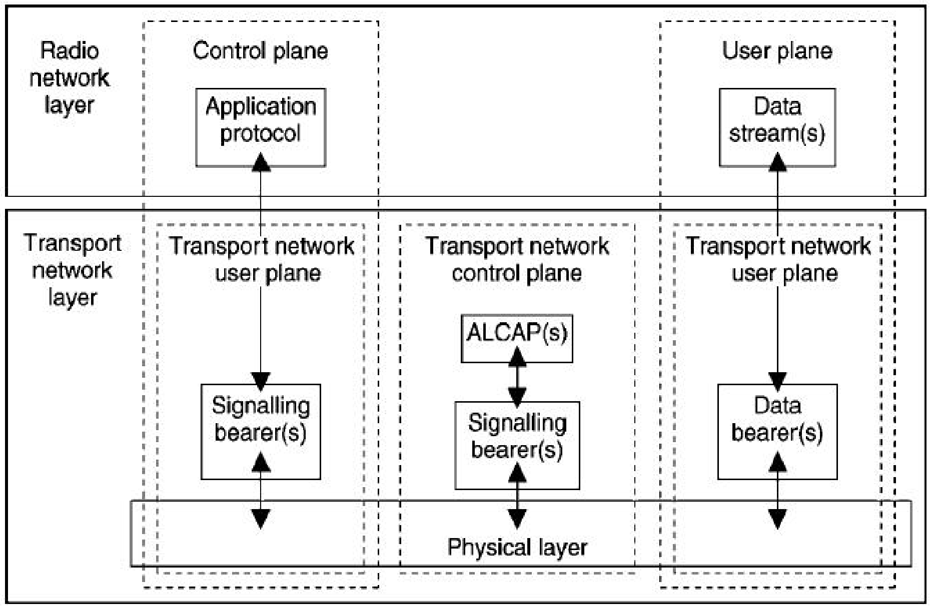

Figure 3.2 : Protocol Model for UTRAN

As shown in Figure 3.2, the protocol structure consists of two main layers, the Radio Network Layer and the Transport Network Layer. All UTRAN-related issues are visible only in the Radio Network Layer, and the Transport Network Layer represents standard transport technology that is selected to be used for UTRAN but without any UTRAN-specific changes. The Control Plane is used for all UMTS-specific control signalling. All information sent and received by the user, such as the coded voice in a voice call or the packets in an Internet connection, are transported via the User Plane. The User Plane includes the Data Stream(s), and the Data Bearer(s) for the Data Stream(s). The Transport Network Control Plane is used for all control signalling within the Transport Layer. The Transport Network Control Plane is a plane that acts between the Control Plane and the User Plane.

3.3 WCDMA

WCDMA is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system, i.e. user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes. In order to support very high bit rates (up to 2 Mbps), the use of a variable spreading factor and multi-code connections is supported. The chip rate of 3.84 Mcps leads to a carrier bandwidth of approximately 5 MHz. The wide carrier bandwidth of WCDMA supports high user data rates and also has certain performance benefits, such as increased multipath diversity. WCDMA supports highly variable user data rates, in other words the concept of obtaining Bandwidth on Demand (BoD) is well supported. The user data rate is kept constant during each 10 ms frame. However, the data capacity among the users can change from frame to frame. This fast radio capacity allocation should typically be controlled by the network to achieve optimum throughput for packet data services. WCDMA supports two basic modes of operation: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). In the FDD mode, separate 5 MHz carrier frequencies are used for the uplink and downlink respectively, whereas in TDD only one 5 MHz is timeshared between the uplink and downlink. Uplink is the connection from the mobile to the base station, and downlink is from the base station to the mobile. Fast power control is one of the most important aspects in WCDMA. Without it, a single overpowered mobile could block a whole cell. Figure 3.3 show the problem and the solution in the form of closed loop transmission power control. Mobile stations MS1 and MS2 operate within the same frequency, separable at the base station only by their respective spreading/coding codes. It may happen that MS1 at the cell edge suffers a path loss, say 70 dB above that of MS2 which is near the base station BS. If there were no mechanism for MS1 and MS2 to be power-controlled to the same level at the base station, MS2 could easily overshot MS1 and thus block a large part of the cell, giving rise to the so-called near-far problem. The optimum strategy in the sense of maximizing capacity is to equalise the received power per bit of all mobile stations at any times.

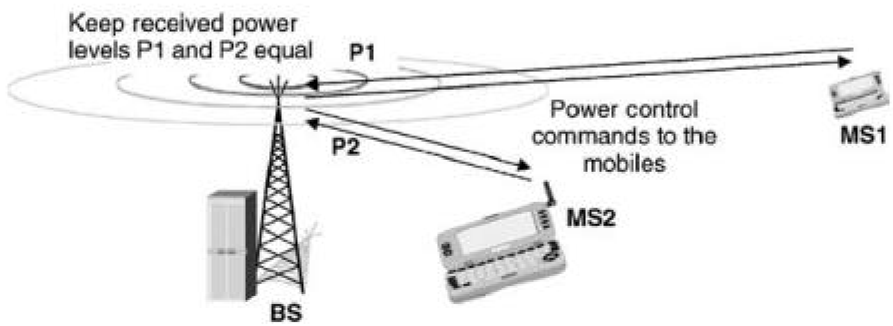

Figure 3.3 : Power Control

If the measured SIR is higher than the target SIR, the base station will order the mobile station to reduce the power; if it is too low it will order the mobile station to increase its power. This measure-command-react cycle is executed at a rate of 1500 times per second (1.5 kHz) for each mobile station and thus operates faster than any significant change of the path. The same closed loop power control technique is also used on the downlink, though here the motivation is different: on the downlink there is no near-far problem due to the one-to-many scenario. It is, however, desirable to provide a marginal amount of additional power to mobile stations at the cell edge, as they suffer from increased other-cell interference [1].

In addition to spreading, part of the process in the transmitter is the scrambling operation. This is needed to separate terminals or base stations from each other. Scrambling is used on top of spreading, so it does not change the signal bandwidth but only makes the signals from different sources separable from each other. With scrambling, it would not matter if the actual spreading were performed with identical codes for several transmitters. Figure 3.4 shows the relationship of the chip rate in the channel to spreading and scrambling. As the chip rate is already achieved in spreading by the channelisation codes, the symbol rate is not affected by the scrambling.

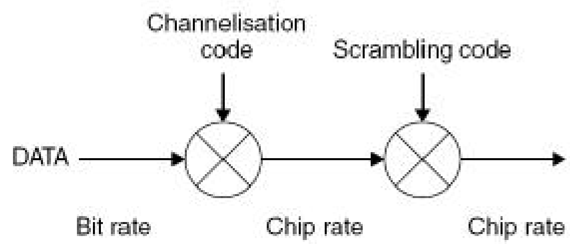

Figure 3.4 : Spreading and Scrambling

Transmissions from a single source are separated by channelisation codes, i.e. downlink connections within one sector and the dedicated physical channel in the uplink from one terminal. The spreading/channelisation codes of UTRAN are based on the Orthogonal Variable Spreading Factor (OVSF). The use of OVSF codes allows the spreading factor to be changed and orthogonality between different spreading codes of different lengths to be maintained. The codes are picked from the code tree, which is illustrated in Figure 3.5. In case the connection uses a variable spreading factor, the proper use of the code tree also allows despreading according to the smallest spreading factor. This requires only that channelisation codes are used from the branch indicated by the code used for the smallest spreading factor. The downlink orthogonal codes within each base station are managed by the radio network controller (RNC) in the network.

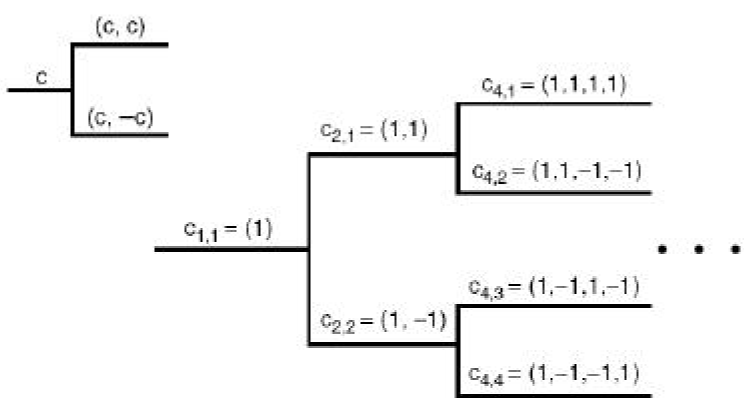

Figure 3.5 : Spreading/Channelisation code tree of UTRAN

3.4 UMTS Channels

Logical channels allow communication between the RLC and MAC layers in UTRAN, and they are characterised by the type of information that is being transferred across these layers. As a result, there are logical channels for the transfer of user traffic, Traffic Channels, and also logical channels for the transfer of control information, Control Channels, which can be either dedicated to specific users or common to a set or to all of them [3]. Logical channels are mapped onto transport channels in the MAC layer. In UTRAN the data generated at higher layers is carried over the air with transport channels, which are mapped in the physical layer to different physical channels. The physical layer is required to support variable bit rate transport channels to offer bandwidth-on-demand services, and to be able to multiplex several services to one connection. Each transport channel is accompanied by the Transport Format Indicator (TFI) at each time event at which data is expected to arrive for the specific transport channel from the higher layers. The physical layer combines the TFI information from different transport channels to the Transport Format Combination Indicator (TFCI). The TFCI is transmitted in the physical control channel to inform the receiver which transport channels are active for the current frame; the exception to this is the use of Blind Transport Format Detection (BTFD) that will be covered in connection with the downlink dedicated channels. The TFCI is decoded appropriately in the receiver and the resulting TFI is given to higher layers for each of the transport channels that can be active for the connection. The interface between physical and higher layers is represented by the Iub-interface between the Node B and RNC. Two types of transport channel exist: Dedicated Channels and Common Channels. The main difference between them is that a common channel is a resource divided between all or a group of users in a cell, instead a dedicated channel resource, identified by a certain code on a certain frequency, is reserved for a single user only [1], [3].

3.4.1 Logical Channels

The most important Control Logical Channels are:

Broadcast Control Channel
Broadcast Control Channel (BCCH) carries control information that is broadcast to all the users of a given cell in the form of System Information messages. Such information includes cell specific parameters (e.g. cell identifiers, code sequences, timers, etc.) that must be known by the UE before trying to camp on a given cell. This channel is only defined in the downlink direction. BCCH is mapped onto BCH Transport Channel.

Paging Control Channel
Paging Control Channel (PCCH) is used to notify incoming calls or messages to the users in a given area. All the UEs in idle mode should listen to this channel periodically. This channel is only defined in the downlink direction. PCCH is mapped onto PCH Transport Channel.

Dedicated Control Channel
Dedicated Control Channel (DCCH) transfers signalling information corresponding to a specific UE. It is a point-to-point bi-directional channel that exists for each UE that has a RRC connection with the RNC. Examples of messages that are transferred through this logical channel are connection establishment messages, radio resource control messages or measurement reports. DCCH is mapped onto DCH, RACH and CPCH transport channels.

Common Control Channel
Common Control Channel (CCCH) would be equivalent to the DCCH channel but for UEs that do not have yet a RRC connection with the RNC and by users executing cell reselection procedures while transmitting in common channels. As a result, the UE should make use of shared physical and transport channels including the corresponding UE identity in the transmitted messages. An example of the utilisation of the CCCH would be the initial message that is transmitted by a UE during a connection establishment and the corresponding channel allocation response from the network. CCCH is mapped onto RACH transport channel.

Two types of Logical Traffic Channels are defined:

Dedicated Traffic Channel
Dedicated Traffic Channel (DTCH) is defined in the user plane and transfers the information corresponding to a given service dedicated to a single user. It exists both in the uplink and downlink direction. Different DTCH channels may coexist for a given UE whenever several services are provided simultaneously (e.g. data and voice connections). DTCH is mapped onto DCH, RACH and CPCH transport channels.

Common Traffic Channel
Common Traffic Channel (CTCH) carries dedicated user information to a group of UEs in a given cell (e.g. for the transfer of SMS Cell Broadcast Messages providing information depending on the geographical area). It is a point-to-multipoint unidirectional channel.

3.4.2 Transport Channels

UMTS Release '99 has only one dedicated transport channels:

Dedicated Channel
The only dedicated transport channel is the Dedicated Channel (DCH). The dedicated transport channel carries all the information intended for the given user coming from layers above the physical layer, including data for the actual service as well as higher layer control information. The content of the information carried on the DCH is not visible to the physical layer, thus higher layer control information and user data are treated in the same way. The dedicated transport channel is characterised by features such as fast power control, fast data rate change on a frame-by-frame basis, and the possibility of transmission to a certain part of the cell or sector with varying antenna weights with adaptive antenna systems.

UMTS Release '99 has six different common transport channels:

Broadcast Channel

The Broadcast Channel (BCH) is a transport channel that is used to transmit information specific to the UTRA network or for a given cell. One terminal which wants to register to the cell needs to decode the broadcast channel.

Forward Access Channel

The Forward Access Channel (FACH) is a downlink transport channel that carries control information to terminals known to be located in the given cell. This is used, for example, after a random access message has been received by the base station. It is also possible to transmit data packets on the FACH. There can be more than one FACH in a cell. One of the forward access channels must have such a low bit rate that it can be received by all the terminals in the cell area. With more than one FACH, the additional channels can have a higher data rate. The FACH does not use fast power control, and the messages transmitted need to include in band identification information to ensure their correct receipt. The FACH, carried on the secondary common control physical channel (S-CCPCH) can be used for downlink packet data as well [2].

Paging Channel

The Paging Channel (PCH) is a downlink transport channel that carries data relevant to the paging procedure, that is, when the network wants to initiate communication with the terminal. The terminals must be able to receive the paging information in the whole cell area.

Random Access Channel

The Random Access Channel (RACH) is an uplink transport channel intended to be used to carry control information from the terminal, such as requests to set up a connection. It can also be used to send small amounts of packet data from the terminal to the network. For proper system operation the random access channel must be heard from the whole desired cell coverage area, which also means that practical data rates have to be rather low, at least for the initial system access and other control procedures.

Uplink Common Packet Channel

The uplink common packet channel (CPCH) is an extension to the RACH channel that is intended to carry packet-based user data in the uplink direction. The reciprocal channel providing the data in the downlink direction is the FACH. CPCH uses fast power control. The uplink CPCH transmission may last several frames in contrast with one or two frames for the RACH message.

Downlink Shared Channel

The downlink shared channel (DSCH) is a transport channel intended to carry dedicated user data and/or control information; it can be shared by several users. In many respects it is similar to the forward access channel, although the shared channel supports the use of fast power control as well as variable bit rate on a frame-by-frame basis. The DSCH does not need to be heard in the whole cell area and can employ the different modes of transmit antenna diversity methods that are used with the associated downlink DCH. The downlink shared channel is always associated with a downlink DCH.

3.4.3 Physical Channel

Following there is a brief overview of the most important physical channels:

Dedicated Physical Data Channel
The Dedicated Physical Data Channel (DPDCH) carries the information of a DCH transport channel. It exists both in the uplink and downlink directions and makes use of closed loop power control [3].

Dedicated Physical Control Channel
The Dedicated Physical Control Channel (DPCCH) is related to a DPDCH and transmits physical layer signalling information (e.g. power control commands and synchronisation sequences).

Primary Common Control
The Primary Common Control Physical Channel (P-CCPCH) only exists in the downlink direction and has a fixed channel bit rate of 30 kb/s, corresponding to a spreading factor of 256. It is used to carry the BCH transport channel.

Secondary Common Control Physical Channel
The Secondary Common Control Physical Channel (Secondary CCPCH) carries two different common transport channels: the Forward Access Channel (FACH) and the Paging Channel (PCH). The two channels can share a single Secondary CCPCH or can use different physical channels. This means that in the minimum configuration each cell has at least one Secondary CCPCH. The spreading factor used in a Secondary CCPCH is fixed and determined according to the maximum data rate. The maximum data rate usable is naturally dependent on the terminal capabilities [2].

Synchronisation Channel
The Synchronisation Channel (SCH) is used for cell search and is the first channel that a terminal must detect before being able to measure a new cell. It allows the synchronisation at frame and time slot levels as well as the determination of the code sequence being used by the P-CCPCH channel that contains the BCH.

Common Pilot Channel
The Common Pilot Channel (CPICH) is used by the terminals to make power measurements of the different cells. The measured level of this channel determinates whether or not the corresponding cell can be used.

Physical Random Access Channel
The Physical Random Access Channel (PRACH) is used in the uplink direction and carries the RACH transport channel.

Physical Common Packet Channel
The Physical Common Packet Channel (PCPCH) exists in the uplink direction and transmits the CPCH transport channel.

Physical Downlink Shared Channel
The Physical Downlink Shared Channel (PDSCH) carries the DSCH transport channel. Different bit rates are available.

3.4.4 Mapping of Logical Channels onto the Transport Channels

In Downlink, the following connections between logical channels and transport channels exist [4]:

- BCCH can be mapped to BCH;
- BCCH can be mapped to FACH;
- BCCH can be mapped to HS-DSCH (in FDD mode only);
- PCCH can be mapped to PCH;
- PCCH can be mapped to HS-DSCH (in FDD mode only);
- CCCH can be mapped to FACH;
- CCCH can be mapped to HS-DSCH (in FDD mode only);
- DCCH can be mapped to FACH;
- DCCH can be mapped to DSCH (in TDD mode only);
- DCCH can be mapped to HS-DSCH;
- DCCH can be mapped to DCH;
- MCCH can be mapped to FACH;
- MSCH can be mapped to FACH;
- DTCH can be mapped to FACH;
- DTCH can be mapped to DSCH (in TDD mode only);
- DTCH can be mapped to HS-DSCH;
- DTCH can be mapped to DCH;
- CTCH can be mapped to FACH;
- MTCH can be mapped to FACH;
- SHCCH can be mapped to FACH (in TDD mode only);
- SHCCH can be mapped to DSCH (in TDD mode only).

3.4.5 Mapping of Transport Channels onto the Physical Channels

The organisation of the radio interface protocol stack in logical, transport and physical channels constitutes a flexible architecture so that the network operator can handle in a different way the different data flows that circulate through the different layers of the stack by establishing the appropriate mappings between the three types of channels. As a result, and depending on the nature of the transmitted information, its required quality and the volume of data, different transport and physical channels can be used for the same logical channel [3]. The mapping between transport and physical channels is given in Figure 3.6.

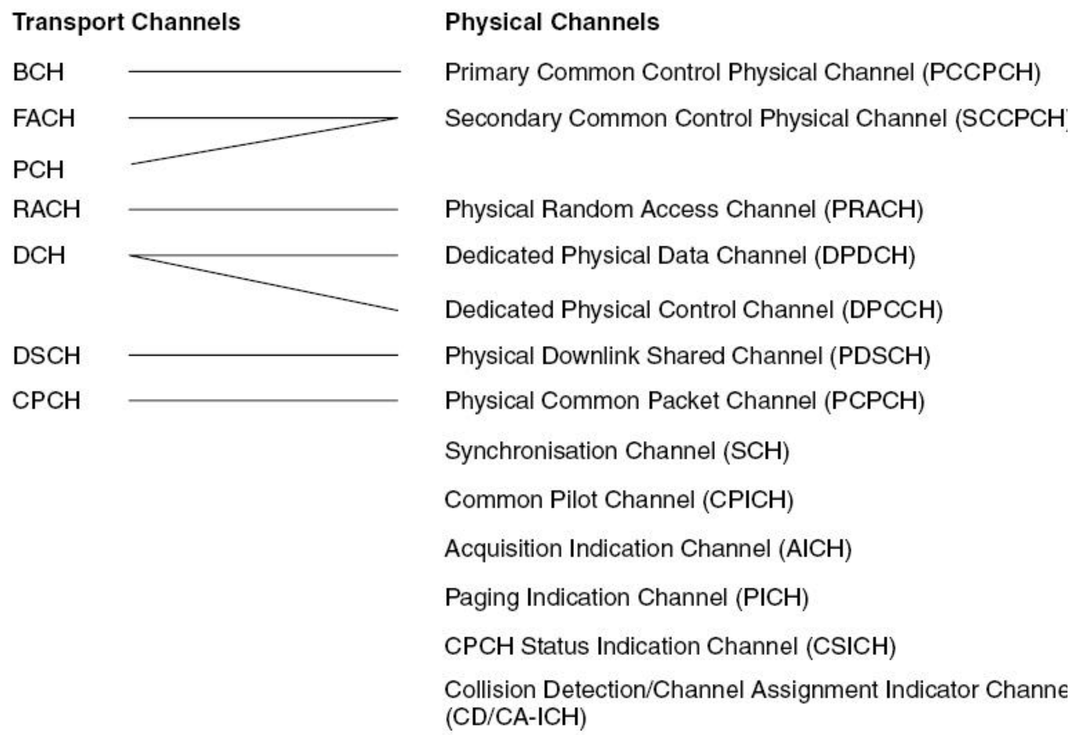

Figure 3.6: Channel Mapping

3.5 Radio Interface Protocols

The radio interface protocols are needed to set up, reconfigure and release the Radio Bearer services (including the UTRA FDD/TDD service). In the control plane, Layer 2 contains two sub-layers–Medium Access Control (MAC) protocol and Radio Link Control (RLC) protocol. In the user plane, in addition to MAC and RLC, two additional service-dependent protocols exist: Packet Data Convergence Protocol (PDCP) and Broadcast/Multicast Control Protocol (BMC). Layer 3 consists of one protocol, called Radio Resource Control (RRC), which belongs to the control plane [1] [3]. The overall radio interface protocol architecture is shown in Figure 3.7.

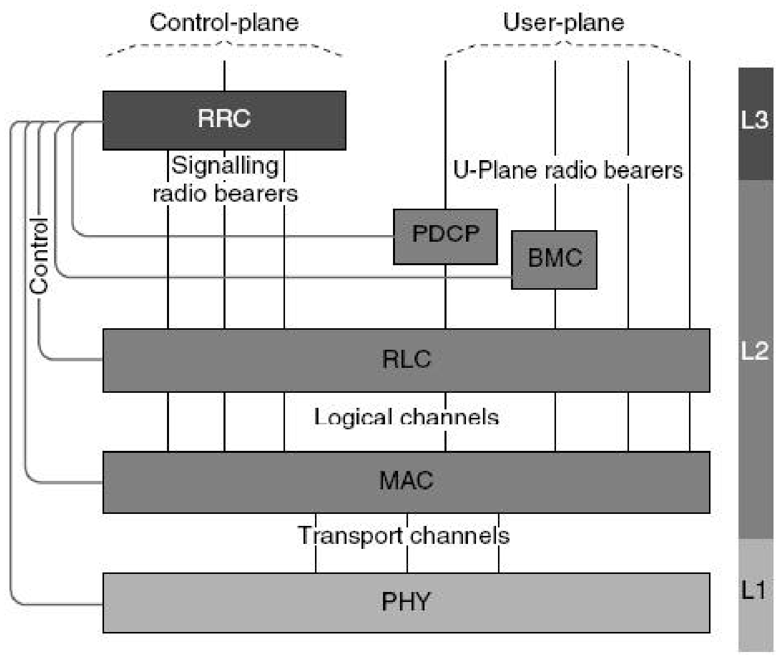

Figure 3.7 : UTRA FDD Radio Interface protocol architecture

The functions of the MAC layer include:

- Mapping between logical channels and transport channels.
- Selection of appropriate Transport Format (from the Transport Format Combination Set) for each Transport Channel, depending on the instantaneous source rate.
- Priority handling between data flows of one UE. This is achieved by selecting 'high bit rate' and 'low bit rate' transport formats for different data flows.
- Priority handling between UEs by means of dynamic scheduling. A dynamic scheduling function may be applied for common and shared downlink transport channels FACH and DSCH.
- Identification of UEs on common transport channels. When a common transport channel (RACH, FACH or CPCH) carries data from dedicated-type logical channels (DCCH, DTCH), the identification of the UE (Cell Radio Network Temporary Identity (C-RNTI) or UTRAN Radio Network Temporary Identity (U-RNTI)) is included in the MAC header.
- Multiplexing/demultiplexing of higher layer PDUs into/from transport blocks delivered to/from the physical layer on common transport channels.
- Multiplexing/demultiplexing of higher layer PDUs into/from transport block sets delivered to/from the physical layer on dedicated transport channels.
- Traffic volume monitoring. MAC receives RLC PDUs together with status information on the amount of data in the RLC transmission buffer. MAC compares the amount of data corresponding to a transport channel with the thresholds set by RRC. If the amount of data is too high or too low, MAC sends a measurement report on traffic volume status to RRC. The RRC can also request MAC to send these

measurements periodically. The RRC uses these reports for triggering reconfiguration of Radio Bearers and/or Transport Channels.

- Dynamic Transport Channel type switching. Execution of the switching between common and dedicated transport channels is based on a switching decision derived by RRC.
- Ciphering. If a radio bearer is using transparent RLC mode, ciphering is performed in the MAC sub-layer (MAC-d entity). Ciphering is a XOR operation where data is XORed with a ciphering mask produced by a ciphering algorithm.
- Access Service Class (ASC) selection for RACH transmission. The PRACH resources may be divided between different Access Service Classes in order to provide different priorities of RACH usage.

The functions of the RLC layer are:

- Segmentation and reassembly. This function performs segmentation/reassembly of variable-length higher layer PDUs into/from smaller RLC Payload Units (P Us).
- Concatenation. If the contents of an RLC SDU do not fill an integral number of RLC PUs, the first segment of the next RLC SDU may be put into the RLC PU in concatenation with the last segment of the previous RLC SDU.
- Padding. When concatenation is not applicable and the remaining data to be transmitted does not fill an entire RLC PDU of given size, the remainder of the data field is filled with padding bits.
- Transfer of user data. RLC supports acknowledged, unacknowledged and transparent data transfer.
- Error correction. This function provides error correction by retransmission in the acknowledged data transfer mode.
- In-sequence delivery of higher layer PDUs.
- Duplicate detection. This function detects duplicated received RLC PDUs and ensures that the resultant higher layer PDU is delivered only once to the upper layer.
- Flow control. This function allows an RLC receiver to control the rate at which the peer RLC transmitting entity may send information.
- Sequence number check (Unacknowledged data transfer mode). This function guarantees the integrity of reassembled PDUs and provides a means of detecting corrupted RLC SDUs through checking the sequence number in RLC PDUs when they are reassembled into an RLC SDU. A corrupted RLC SDU is discarded.
- Protocol error detection and recovery. This function detects and recovers from errors in the operation of the RLC protocol.
- Ciphering
- Suspend/resume function for data transfer.

The main PDCP functions are:

- Compression of redundant protocol control information at the transmitting entity, and decompression at the receiving entity.
- Transfer of user data. This means that the PDCP receives a PDCP SDU from the non-access stratum and forwards it to the appropriate RLC entity and vice versa.

- Support for lossless SRNS relocation. In practice this means that those PDCP entities which are configured to support lossless SRNS relocation have PDU sequence numbers, which, together with unconfirmed PDCP packets are forwarded to the new SRNC during relocation.

The main functions of the BMC protocol are:

- Storage of Cell Broadcast messages. The BMC in RNC stores the Cell Broadcast messages received over the CBC–RNC interface for scheduled transmission.
- Traffic volume monitoring and radio resource request for CBS.
- Scheduling of BMC messages.
- Transmission of BMC messages to UE.
- Delivery of Cell Broadcast messages to the upper layer.

The main RRC functions are:

- Broadcast of system information;
- Paging;
- Initial cell selection and reselection in idle mode;
- Establishment, maintenance and release of an RRC connection between the UE and UTRAN;
- Control of Radio Bearers, transport channels and physical channels;
- Control of security functions (ciphering and integrity protection);
- Integrity protection of signalling messages;
- UE measurement reporting and control of the reporting;
- RRC connection mobility functions;
- Support of SRNS relocation;
- Support for downlink outer loop power control in the UE;
- Open loop power control;
- Cell broadcast service related functions;
- Support for UE Positioning functions.

3.6 UMTS Evolution

The development of the first UMTS specifications was done at the same time that Internet was becoming progressively more and more popular and the IP technology began to be used not only for the transport of data services but also for speech and video services, thus becoming a new paradigm for the deployment of multiservice networks. The response of the UMTS system to this expansion of IP technology is given in the releases that followed the initial Release '99, and whose main purpose was the progressive transformation of UMTS in an all IP network that was more efficient than the coexistence of two separated networks for the CS and PS core network domains. In Release '99, the transport technology used between the elements of the UTRAN is ATM. In turn, in the CS domain of the core network, 64 kb/s circuits are used and in the PS domain transmissions are done by means of IP tunnels using GPRS Tunnelling Protocol[1] (GTP).

The first step in the evolution towards an all IP network is Release 4, in which the CS domain of the CN is replaced by an IP or an IP/ATM backbone. The transmission of speech services over this IP backbone introduces important technological challenges that lead to the so-called voice over IP technology. This modification of the core network involves the evolution of MSC in two different components, namely the MSC server, which comprises the call control and mobility control parts of the MSC, thus handling only signalling, and the Media Gateway Function (MGW), which handles the users' data flows.

Release 5 executes the final step to achieving a CN completely based on IP technology by removing the possibility of using ATM in the CS domain. In the new architecture, the provision of real time IP multimedia service is done by means of the inclusion of a new CN domain, namely the IP Multimedia Subsystem (IMS), which is connected to the GGSN and the MGW, and makes use of the Session Initiation Protocol[2] (SIP) as a means of establishing multimedia sessions between users supporting user mobility and call redirection. Another of the changes introduced by Release 5 in the CN consists of the integration of the functionalities of the HLR and the AuC in the Home Subscriber Server (HSS), which contains the subscription related information for each user in order to support the call and session handling. The Release 5 does not limit the changes to the CN, and introduces an important modification at the radio interface. In particular, a new packet access mechanism over WCDMA, denoted as HSDPA (High Speed Downlink Packet Access) is defined. HSDPA supports much higher bit rates up to around 10 Mb/s by means of an additional modulation scheme and the implementation of fast packet scheduling and hybrid retransmission mechanisms, and coexists with the radio access mechanisms existing in previous releases.

The final objective of an all IP architecture like the one defined in Release 5 is the inclusion of the IP technology in the radio access network. Due to the important modifications that such a change requires, this inclusion was postponed to the Release 6. The existence of an all IP network including the radio access part facilitates the integration of different radio access technologies operating over a unique backbone technology and therefore enables the development of heterogeneous networks that integrate the UTRAN and GERAN technologies with others [3].

3.6.1 UTRAN Evolution

Release '99 architecture is characterised by having only one MSC and one SGSN connected to the RNC, i.e. only one Iu PS and Iu CS interface in the RNC. This limitation is overcome

1 GPRS Tunnelling Protocol (GTP) allows end users of a GSM or UMTS network to move from place to place whilst continuing to connect to the internet as if from one location at the GGSN. It does this by carrying the subscriber's data from the subscriber's current SGSN to the GGSN which is handling the subscriber's session.

2 The Session Initiation Protocol is a signalling protocol used for establishing sessions in an IP network. A session could be a simple two-way telephone call or it could be a collaborative multi-media conference session.

in the Release 5 specification with the introduction of the Iu flex (abbreviation from the word 'flexible') concept, that allows one RNC to have more than one Iu PS and Iu CS interface instances with the core. The main benefits of this feature are to introduce the possibility of load sharing between the core network nodes, and to increase the possibility to anchor the MSC and SGSN in case of SRNS relocation.

Iu interface has also been scheduled to be part of the GSM/EDGE Radio Access Network (GERAN) in Release 5. This allows reusing the 3G Core Network also for the GSM/EDGE radio interface, but it also allows a more optimised interworking between the two radio technologies. It has also been introduced Common Radio Resource Management (CRRM) between UTRAN and GERAN.

3.6.2 UMTS Core Network Architecture Evolution

The Release 5 architecture is shown in Figure 3.8.

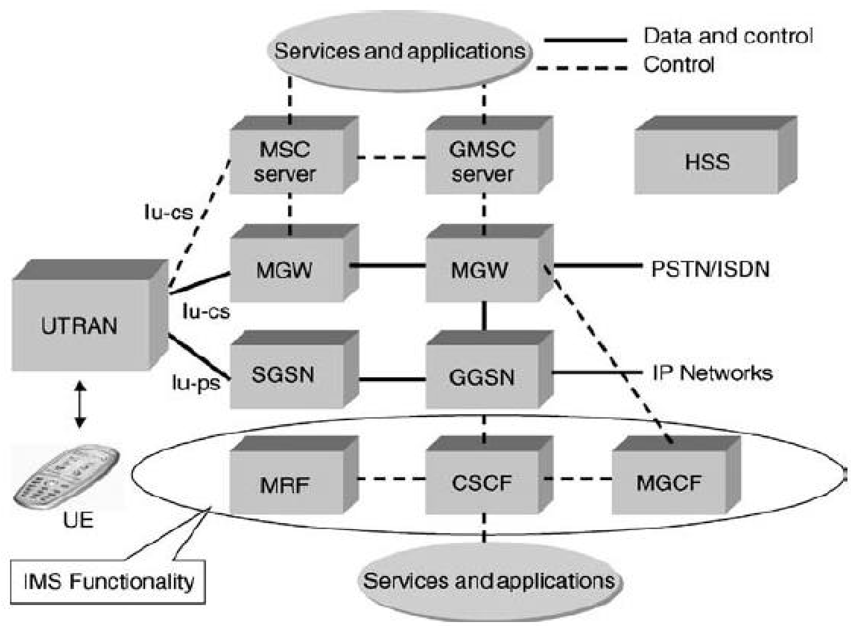

Figure 3.8: Release 5 UMTS Architecture

The following elements have experienced changes in the CS-domain for Release 4 [1]. The MSC or GMSC server, takes care of the control functionality as MSC or GMSC respectively, but the user data goes via the MGW. One MSC/GMCS server can control multiple MGWs, which allows better scalability of the network when, e.g., the data rates increase with new data services. In that case, only the number of MGWs needs to be increased. MGW performs the actual switching for user data and network interworking processing.
In the PS-domain, the SGSN and GGSN are as in Release '99 with some enhancements, but for the IP-based service delivery, the IMS has now the following key elements included:

- Media Resource Function (MRF) which, e.g., controls media stream resources or can mix different media streams. The standard defines further the detailed functional split for MRF.
- Call Session Control Function (CSCF), which acts as the first contact point to the terminal in the IMS. The CSCF covers several functionalities from handling of the session states to being a contact point for all IMS connections intended for a single user and acting as a firewall towards other operator's networks.
- Media Gateway Control Function (MGCF), to handle protocol conversions. This may also control a service coming via the CS domain and perform processing in an MGW, e.g. for echo cancellation.

3.7 HSPA

3.7.1 HSDPA

A key characteristic of HSDPA is the use of Shared-Channel Transmission. Shared channel transmission implies that a certain fraction of the total downlink radio resources available within a cell, channelization codes and transmission power in case of WCDMA, is are seen as a common resource that is dynamically shared between users, primarily in the time domain. The use of shared-channel transmission, in WCDMA implemented through the High-Speed Downlink Shared Channel (HS-DSCH), enables the possibility to rapidly allocate a large fraction of the downlink resources for transmission of data to a specific user [2]. This is suitable for packet-data applications which typically have bursty characteristics and thus rapidly varying resource requirements. HS-DSCH is a transport channel mapped onto High Speed Physical Downlink Shared Channel (HS-PDSCH). The HS-DSCH code resource consists of a set of channelization codes of spreading factor 16 where the number of codes available for HS-DSCH transmission is configurable between 1 and 15. It is possible to allocate more than one code for the same user and more code means that higher rates are allowed. The dynamic allocation of the HS-DSCH code resource for transmission to a specific user is done on 2 ms TTI basis. Those features of HS-DSCH are shown in Figure 3.9.

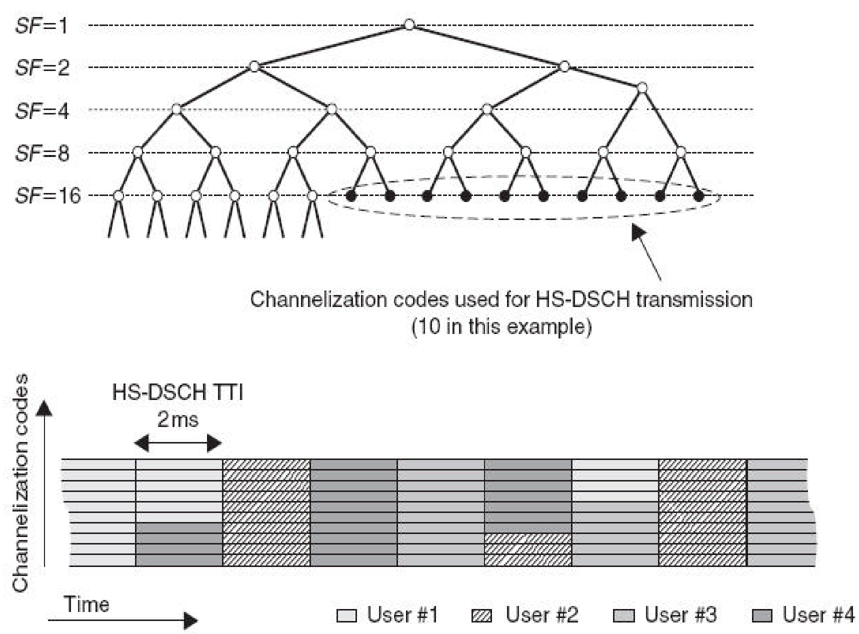

Figure 3.9 : HS-DSCH Features

The use of such a short TTI for HSDPA reduces the overall delay and improves the tracking of fast channel variations exploited by the rate control and the channel-dependent scheduling. In addition to being allocated a part of the overall code resource, a certain part of the total available cell power should also be allocated for HS-DSCH transmission. Note that the HS-DSCH is not power controlled but rate controlled. This allows the remaining power, after serving other channels, to be used for HS-DSCH transmission and enables efficient exploitation of the overall available power resource.

Scheduling controls to which user the shared-channel transmission is directed at a given time instant. In each TTI, the scheduler decides to which user(s) the HS-DSCH should be transmitted and, in close cooperation with the rate-control mechanism, at what data rate. Since the radio conditions for the radio links to different UEs within a cell typically vary independently, at each point in time there is almost always a radio link whose channel quality is near its peak. As this radio link is likely to have good channel quality, a high data rate can be used for this radio link. This translates into a high system capacity. The gain obtained by transmitting to users with favorable radio-link conditions is commonly known as multi-user diversity. In addition to the channel conditions, traffic conditions are also taken into account by the scheduler. For example, there is obviously no purpose in scheduling a user with no data awaiting transmission, regardless of whether the channel conditions are beneficial or not. Furthermore, some services should preferably be given higher priority. As an example, streaming services should be ensured a relatively constant long-term data rate while background services such as file download have less stringent requirements on a constant long-term data rate.

For the purpose of HS-DSCH link adaptation, the UE periodically send a Channel Quality Indicator (CQI) to the serving HS-DSCH cell on the uplink. The CQI indicates the maximum transport block size that can be received correctly. This information is signaled via a CQI index in the range from 0 to 31. Actually each value of CQI corresponds also to a modulation and a number of orthogonal codes. These parameters together determinate the bit rate and this means that each CQI value corresponds to a bit rate. For HSDPA Release 6, rate control is implemented by dynamically adjusting the channel coding rate as well as dynamically selecting between QPSK and 16QAM modulation in function of the CQI received. In Release 7, 64QAM modulation has also been included. Higher-order modulation such as 16QAM allows for higher bandwidth utilization than QPSK, but requires higher received SINR. Consequently, 16QAM is mainly useful in advantageous channel conditions. The data rate is selected independently for each 2 ms TTI by the Node B and the rate control mechanism can therefore track rapid channel variations. Fast Hybrid ARQ (H-ARQ) with soft combining allows the terminal to request retransmission of erroneously received transport blocks. Soft combining implies that the terminal does not discard soft information in case it cannot decode a transport block as in traditional Hybrid ARQ protocols, but combines soft information from previous transmission attempts with the current retransmission to increase the probability of successful decoding. Incremental Redundancy (IR) is used as the basis for soft combining in HSDPA, that is the retransmissions may contain parity bits not included in the original transmission.

Therefore, HSDPA introduces a new MAC sub-layer in the Node B, the MAC-hs, responsible for scheduling, rate control and H-ARQ protocol operation. Hence, apart from the necessary enhancements to the RNC such as admission control of HSDPA users, the introduction of HSDPA mainly affects the Node B [2].

3.7.2 HSUPA

Enhanced Uplink, also known as High-Speed Uplink Packet Access (HSUPA), has been introduced in WCDMA Release 6. At the core of Enhanced Uplink are two basic technologies used also for HSDPA: fast scheduling and fast H-ARQ with soft combining. For similar reasons as for HSDPA, HSUPA also introduces a short 2 ms uplink TTI. These enhancements are implemented in WCDMA through a new transport channel, the Enhanced Dedicated Channel (E-DCH). Although the same technologies are used both for HSDPA and Enhanced Uplink, there are fundamental differences between them, which have affected the detailed implementation of the features:

- In the downlink, the shared resources are transmission power and the code space, both of which are located in one central node, the Node B. In the uplink, the shared resource is the amount of allowed uplink interference, which depends on the transmission power of multiple distributed nodes, the UEs.

- The scheduler and the transmission buffers are located in the same node in the downlink, while in the uplink the scheduler is located in the Node B while the data buffers are distributed in the UEs. Hence, the UEs need to signal buffer status information to the scheduler.
- The WCDMA uplink, also with Enhanced Uplink, is inherently non-orthogonal, and subject to interference between uplink transmissions within the same cell. This is in contrast to the downlink, where different transmitted channels are orthogonal. Fast power control is therefore essential for the uplink to handle the near-far problem. The HSUPA is transmitted with a power offset relative to the power-controlled uplink control channel and by adjusting the maximum allowed power offset, the scheduler can control the HSUPA data rate. This is in contrast to HSDPA, where a constant transmission power with rate adaptation is used.
- In the downlink, higher-order modulation, which trades power efficiency for bandwidth efficiency, is useful to provide high data rates in some situations, for example when the scheduler has assigned a small number of channelization codes for a transmission but the amount of available transmission power is relatively high. The situation in the uplink is different; there is no need to share channelization codes between users and the channel coding rates are therefore typically lower than for the downlink. Hence, unlike the downlink, higher-order modulation is less useful in the uplink macro-cells and therefore not part of the first release of enhanced uplink.

For Enhanced Uplink, the scheduler is a key element, controlling when and at what data rate the UE is allowed to transmit. The higher the data rate a terminal is using, the higher the terminal's received power at the Node B must be granted to maintain the Eb/No required for successful demodulation. By increasing the transmission power, the UE can transmit at a higher data rate. However, due to the non-orthogonal uplink, the received power from one UE represents interference for other terminals. Hence, the shared resource for Enhanced Uplink is the amount of tolerable interference in the cell. If the interference level is too high, some transmissions in the cell, control channels and non-scheduled uplink transmissions, may not be received properly. On the other hand, a too low interference level may indicate that the full system capacity is not exploited.

Fast H-ARQ with soft combining is used by Enhanced Uplink for basically the same reason as for HSDPA. For each transport block received in the uplink, a single bit is transmitted from the Node B to the UE to indicate successful decoding (ACK) or to request a retransmission of the erroneously received transport block (NAK) [2].

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Chapter 4

Multimedia Broadcast/Multicast Service Aspects

4.1 Introduction

3GPP Release 6 brings efficient support for broadcast services into WCDMA through the introduction of Multimedia Broadcast Multicast Services (MBMS), suitable for applications like mobile TV. With MBMS, multiple terminals may receive the same broadcast transmission instead of the network transmitting the same information individually to each of the users.

Initially, the need for the mobile phones to support a variety of multimedia mobile services at high data rates has led to the definition of 3rd Generation (3G) Mobile Cellular Networks and the choice of WCDMA for the radio access technique. A consequence of using WCDMA is that capacity of 3G systems is not hard limited. This means that an additional user entering the system cannot be blocked because of the limited amount of available channels. If a sufficient number of spreading codes is available, the interference due to increased load will be the main capacity-limiting factor in the network. Later on, the need for efficient data distribution when a large number of users want to receive the same data has led to the definition of Multimedia Broadcast Multicast Service (MBMS) System.

This chapter is organized as follows. The MBMS are described in Section 4.2, then the architecture to support MBMS in Section 4.3, MBMS channels in Section 4.4, MBMS Protocols are presented in Section 4.5, and finally MBMS over HSPA in Section 4.6.

4.2 MBMS Description

There are three types of MBMS User Service:

- Streaming services, which provide a stream of continuous media, i.e. audio and video. For example, if text includes some content on the Internet, a user can easily access the content without entering the URL for himself. It needs time synchronisation.
- File download services, which deliver binary data (file data) over an MBMS bearer. An MBMS client (i.e. UE) activates an appropriate application, and utilises the delivered data.
- Carousel services, which are services that combine aspects of both the Streaming and File download services described above. Similar to the streaming service this service includes time synchronisation. However, the target media of this service is only static media (e.g. text and/or still images). The benefit of this service is that it is possible over a low bit-rate bearer.

MBMS supports multicast/broadcast services in a cellular system, thereby combining multicast and unicast transmissions within a single network. With MBMS, the same content is transmitted to multiple users located in a specific area, the MBMS service area, in a unidirectional way. The MBMS service area typically covers multiple cells, although it can be made as small as a single cell.

Broadcast and multicast describe different, although closely related scenarios:

- The broadcast mode is a unidirectional point-to-multipoint transmission of multimedia data from a single source entity to all users in a broadcast service area. In broadcast, a point-to-multipoint radio resource is set up in each cell being part of the MBMS broadcast area and all users subscribing to the broadcast service simultaneously receive the same transmitted signal. No tracking of users' movement in the radio access network is performed and users can receive the content without notifying the network. Mobile TV is an example of a service that could be provided through MBMS broadcast. The broadcast mode should allow terminals to minimise their power consumption. The reception of the traffic in the broadcast mode is not guaranteed. The receiver may be able to recognize data loss.

- The multicast mode allows the unidirectional point-to-multipoint transmission of multimedia data (e.g. text, audio, picture, video) from a single source point to a multicast group in a multicast service area. The multicast mode is intended to efficiently use radio/network resources e.g. data is transmitted over a common radio channel. In the multicast mode there is the possibility for the network to selectively transmit to cells within the multicast service area which contain members of a multicast group. In multicast, users request to join a multicast group prior to receiving any data. The user movements are tracked and the radio resources are configured to match the number of users in the cell. Each cell in the MBMS multicast area may be configured for point-to-point or point-to-multipoint transmission. In sparsely populated cells with only one or a few users subscribing to the MBMS service, point-to-point transmission may be appropriate, while in cells with a larger number of users, point-to-multipoint transmission is better suited. Multicast therefore allows the network to optimize the transmission type in each cell. An example of a service using the multicast mode could be a football results service for which a subscription is required. Multicast mode generally requires a subscription to the multicast subscription group and then the user joining the corresponding multicast group. The subscription and group joining may be made by the PLMN operator, the user or a third party on their behalf (e.g. company). Multicast mode shall be inter-operable with IETF IP Multicast. This could allow the best use of IP service platforms to help maximize the availability of applications and contents so that current and future services can be delivered in a more efficient manner.

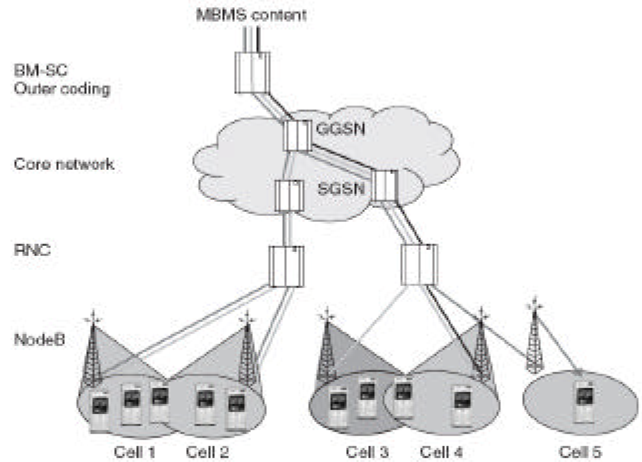

Figure 4.1 : MBMS example

To a large extent, MBMS affects mainly the nodes above the radio-access network. A new node, the Broadcast Multicast Service Center (BM-SC), illustrated in Figure 4.1, is introduced. The BM-SC is responsible for authorization and authentication of content provider, charging, and the overall configuration of the data flow through the core network. It is also responsible for application-level coding. In Figure 4.2, typical phases during an MBMS session are illustrated [1].

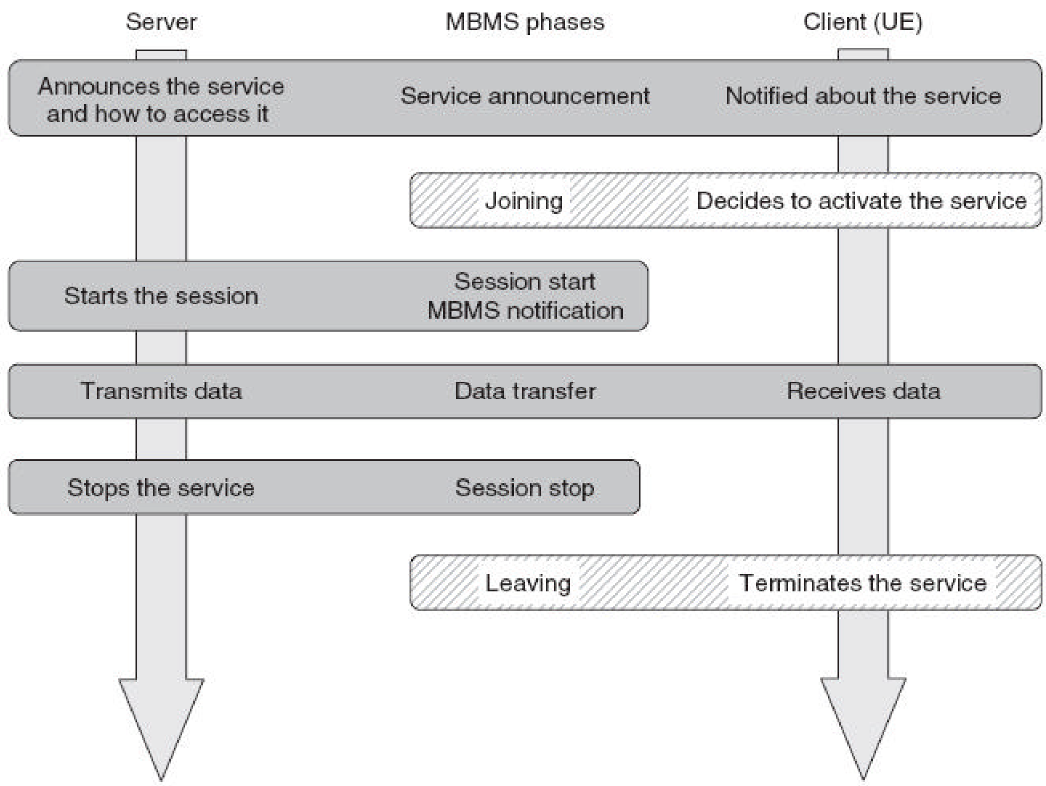

Figure 4.2: Example of typical phases during a MBMS session

First, the service is announced. In case of broadcast, there are no further actions required by the user; the user simply 'tunes' to the channel of interest. In case of multicast, a request to join the session has to be sent to become member of the corresponding MBMS service group and, as such, receive the data. Before the MBMS transmission can start, the BM-SC sends a session-start request to the core network, which allocates the necessary internal resources and request the appropriate radio resources from the radio-access network. All terminals of the corresponding MBMS service group are also notified that content delivery from the service will start. Data will then be transmitted from the content server to the end users. When the data transmission stops, the server will send a session-stop notification. Also, users who want to leave an MBMS multicast service can request to be removed from the MBMS service group [1][2].

One of the main benefits brought by MBMS is the resource savings in the network as a single stream of data may serve multiple users. This is showed in Figure 4.1, where three different services are offered in different areas. As seen in the figure, the data stream intended for multiple users is not split until necessary. For example, there is only a single stream of data sent to all the users in cell 3. This is valid also from a radio-interface perspective, in fact MBMS data transmission should adapt to different RAN capabilities or different radio resource ava ilability, e.g. by reducing the bitrate of the MBMS data. Depending on the number of users that have joined to receive the content via the MBMS, the network can select whether to use point-to-point or point-to-multipoint transmission. In the former case, DCH is used as the transport channel and in the case where several UEs want to receive the same service, FACH is used as the transport channel in a particular cell. On the physical layer, the FACH is mapped on S-CCPCH and DCH respectively of the DPDCH. Obviously, point-to-multipoint transmission puts very different requirements on the radio interface than point-to-point unicast. User-specific adaptation of the radio parameters, such as channel-dependent scheduling or rate control, cannot be used as the signal is intended for multiple users. The transmission parameters such as power must be set taking the worst case user into account as this determines the coverage for the service. Frequent feedback from the users, for example, in the form of Channel Quality Indicator (CQI) reports or H-ARQ status reports, would also consume a large amount of the uplink capacity in cells where a large number of users simultaneously receive the same content. Imagine, for example, a sports arena with thousands of spectators watching their home team playing, all of them simultaneously wanting to receive results from games in other locations whose outcome might affect their home team. Clearly, user-specific feedback would consume a considerable amount of capacity in this case.

The UTRAN shall decide, based on the number of UEs in a particular cell, which mode of MBMS operation to use, and if the situation changes, the network can transfer the UEs between different states of MBMS reception. Typically, there need to be more than just a few UEs to receive the same content in order to make the use of a broadcast channel without power control efficient enough.

From the above discussion, it is clear that MBMS services are power limited and maximizing the diversity without relying on feedback from the users is of key importance. The two main techniques for providing the diversity for MBMS services are:

- Macro-diversity by combining of transmissions from multiple cells.
- Time-diversity against fast fading through a long 80 ms TTI and application level coding.

Fortunately, MBMS services are not delay sensitive and the use of a long TTI is not a problem from the end-user perspective. Additional means for providing diversity can also be applied in the network. Receive diversity in the terminal also improves the performance, but as the 3GPP UE requirements for Release 6 are set assuming single-antenna for UEs, it is hard to exploit this type of diversity in the planning of MBMS coverage .

Combining transmissions of the same content from multiple cells (macro-diversity) provides a significant diversity gain, in the order of 4-6 dB reduction in transmission power compared to single-cell reception. Two combining strategies are supported for MBMS:

- soft combining which combines the soft bits received from the different radio links prior to (Turbo) decoding. In principle, the UE descrambles and RAKE combines the transmission from each cell individually, followed by soft combining of the different radio links. Note that, in contrast to unicast, this macro-diversity gain comes ‘for free’ in the sense that the signal in the neighboring cell is anyway present. Therefore it is better to exploit this signal rather than treat it as interference. However, as WCDMA uses cell-specific scrambling of all data transmissions, the soft combining needs to be performed by the appropriate UE processing. This processing is also responsible for suppressing the interference caused by (non-MBMS) transmission activity in the neighboring cells. To perform soft combining, the physical channels to be combined should be identical. For MBMS, this implies the same physical channel content and structure should be used on the radio links that are soft combined.

- selection combining which decodes the signal received from each cell individually and for each TTI selects one (if any) of the correctly decoded data blocks for further processing by higher layers.

The principles of both are showed in Figure 4.3.

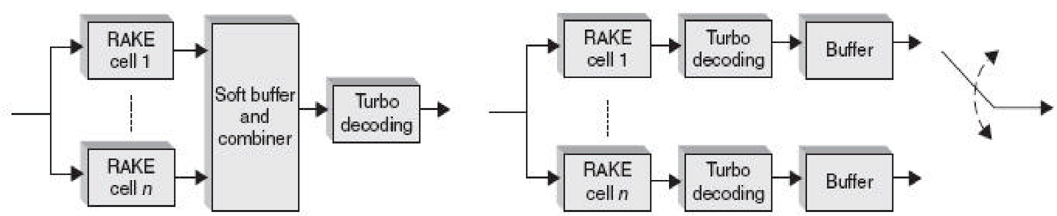

Figure 4.3 : Soft and Selection Combing principles

From a performance perspective, soft combining is preferable as it provides not only diversity gains, but also a power gain as the received power from multiple cells is exploited. Relative to selection combining, the gain is in the order of 2–3 dB [1]. The reason for supporting two different combining strategies is to handle different levels of asynchronism in the network. For soft combining, the soft bits from each radio link have to be buffered until the whole TTI is received from all involved radio links and the soft combining can start, while for selection combining, each radio link is decoded separately and it is sufficient to buffer the decoded information bits from each link. Hence, for a large degree of asynchronism, selection combining requires less buffering in the UE at the cost of an increase in Turbo decoding processing and loss of performance. The UE is informed about the level of synchronism and can, based upon this information and its internal implementation, decide to use any combination scheme as long as it satisfies the minimum performance requirements mandated by the specifications. With similar buffering requirements as for a 3.6 Mbit/s HSDPA terminal, which is the basis for the definition of the UE MBMS requirements, soft combining is possible provided the transmissions from the different cells are synchronized within approximately 80 ms, which is likely to be realistic in most situations.

As mentioned above, the UE capabilities are set assuming similar buffering requirements as for a 3.6 Mbit/s HSDPA terminal. This result in certain limitations in the number of radio links a terminal is required to be able to soft combine for different TTI values and different data rates. This is illustrated in Table 4.1, from which it is also seen that all MBMS-capable UEs can support data rates up to 256 kbit/s.

Table 4.1: UE Radio Link Capabilities

Data rate (on MTCH)	Soft combining		Selection combining	
	Maximum number of RLs	TTI	Maximum number of RLs	TTI
256 kbit/s	3	40	2	40
	≤2	80	1	80
128 kbit/s	≤3	80	3	40
			2	80
			1	80
≤64 kbit/s	≤3	80	≤3	80

As network planning has to be done assuming a certain set of UE capabilities in terms of soft combining, etc., exceeding these capabilities cannot be exploited by the operator. The end user may of course benefit from a more advanced terminal, for example through the possibility for receiving multiple services simultaneously.

Many end-user applications require very low error probabilities, in the order of 10^{-6}. Providing these low error probabilities on the transport channel level can power-wise be quite costly. In point-to-point communications, some form of (hybrid) ARQ mechanism is therefore used to retransmit erroneous packets. HSDPA, for example, uses both a H-ARQ mechanism and RLC retransmissions. In addition, the TCP protocol itself also performs retransmissions to provide virtually error-free packet delivery. However, as previously discussed, broadcast typically cannot rely on feedback, and, consequently, alternative strategies need to be used. For MBMS, application-level forward error correcting coding is used to address this problem. The application-level coding resides in the BM-SC and is thus not part of the radio-access network. With application-level coding, the system can operate at a transport-channel block-error rate in the order of 1–10% instead of fractions of a percent, which significantly lowers transmit power requirement. Systematic Raptor codes have been selected for the application-level coding in MBMS, operating on packets of constant size (48–512 bytes). Raptor codes belongs to a class of Fountain codes, and as many encoding packets as needed can be generated on-the-fly from the source data. For the decoder to be able to reconstruct the information, it only needs to receive sufficiently many coded packets. It does not matter which coded packets it received, in what order they are received, or if certain packets were lost.

In addition to provide additional protection against packet losses and to reduce the required transmission power, the use of application-level coding also simplifies the procedures for UE measurements. For HSDPA, the scheduler can avoid scheduling data to a given UE in certain time intervals. This allows the UE to use the receiver for measurement purposes, for example to tune a different frequency and possible also a different radio access technology. In a broadcast setting, scheduling measurement gaps is cumbersome as different UEs may have different requirements on the frequency and length of the measurement gaps. Furthermore, the UEs need to be informed when the measurement gaps occur. Hence, a different strategy for measurements is adopted in MBMS. The UE measurements are done autonomously, which could imply that a UE sometimes miss (part of) a coded transport block on the physical channel. In some situations, the inner Turbo code is still able to decode the transport channel data, but if this is not the case, the outer application-level code will ensure that no information is lost.

4.3 Architecture to support MBMS

MBMS architecture enables the efficient usage of radio-network and core-network resources, with an emphasis on radio interface efficiency.
MBMS is realized by the addition of a number of new capabilities to existing functional entities of the 3GPP architecture and by addition of a number of new functional entities. In the Figure 4.4 the architecture to support MBMS is showed [3].

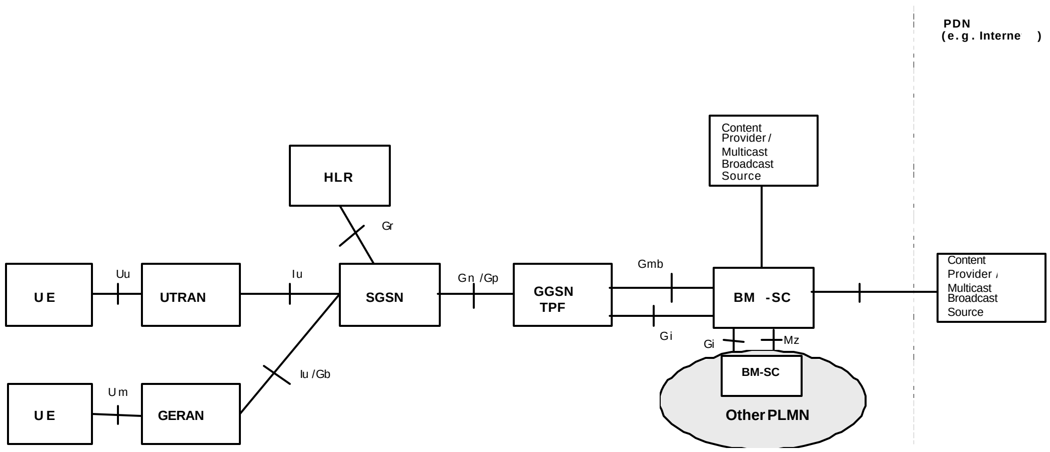

Figure 4.4: Reference architecture to support the MBMS bearer service

The existing PS Domain functional entities (GGSN, SGSN, UTRAN, GERAN and UE) are enhanced to provide the MBMS Bearer Service to deliver IP multicast datagrams to the multiple receivers using minimum network and radio resources. Next there is a brief description of the entities involved in the management of MBMS.

4.3.1 Broadcast Multicast Service Centre (BM-SC)

The BM-SC provides functions for MBMS user service provisioning and delivery. It may serve as an entry point for content provider MBMS transmissions, used to authorize and initiate MBMS Bearer Services within the PLMN and can be used to schedule and deliver MBMS transmissions. Particularly, the BM-SC consists of five sub-functions:

- Service Announcement function;
- Session and Transmission function;
- Proxy and Transport function;
- Membership function;
- Security function.

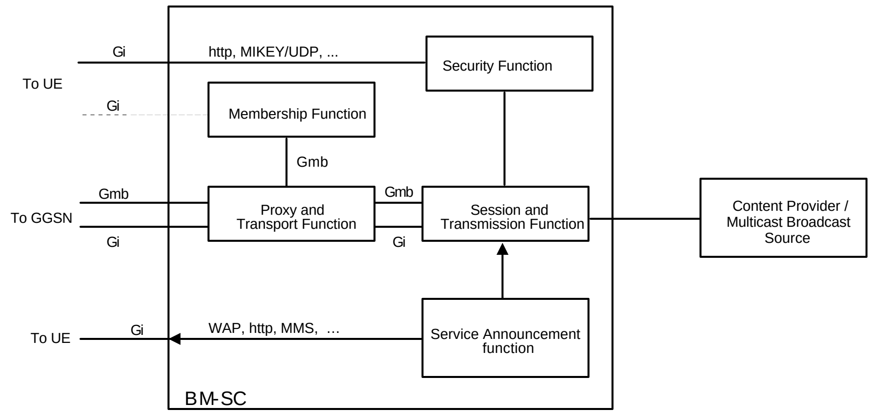

Figure 4.5: BM-SC functional structure

The **BM-SC Service Announcement function** shall be able :

- to provide the UE with media descriptions specifying the media to be delivered as part of an MBMS user service (e.g. type of video and audio encodings);
- to provide the UE with MBMS session descriptions specifying the MBMS sessions to be delivered as part of an MBMS user service (e.g. multicast service identification, addressing, time of transmission, etc.);
- to deliver media and session descriptions by means of service announcements using IETF specified protocols over MBMS multicast and broadcast bearer services. Service announcements, triggered by the BM-SC but not necessarily sent by the BM-SC, should be realized by PUSH mechanism (WAP push), URL (WAP, HTTP), SMS (point-to-point), SMS-CB cell broadcast and other mechanisms could be considered in future releases.

The Service Announcement Function is a user service level function.

The **BM-SC Session and Transmission Function** shall be able:

- to schedule MBMS session transmissions and retransmissions, and label each MBMS session with an MBMS Session Identifier to allow the UE to distinguish the MBMS session retransmissions. The BM-SC Session and Transmission Function allocates a unique TMGI (Temporary Mobile Group Identity) per MBMS bearer service[1]. Each transmission and subsequent retransmission(s) of a specific MBMS session are identifiable by a common MBMS Session Identifier (2-3 Octets) passed at the application layer in the content, and also passed in a shortened form (i.e. the least significant octet) in the MBMS Session Start Request message to the RNCs/BSCs. The full MBMS Session Identifier should be used by the UE to identify an MBMS session when completing point-to-point repair, while the shortened MBMS Session Identifier is included by the RANs in the notification messages for MBMS;
- to provide the GGSN with transport associated parameters such as quality-of-service and MBMS service area;
- to initiate and terminate MBMS bearer resources prior to and following transmission of MBMS data;

1 The structure of the TMGI is defined in 3GPP TS 23.003.

- to send MBMS data. It could also apply favorable error resilient schemes e.g. specialized MBMS codecs or Forward Error Correction schemes;
- to authenticate and authorize external sources and accept content from them.

The Session and Transmission Function is a user service level function and it triggers bearer level functions when MBMS sessions are scheduled.

The **BM-SC Proxy and Transport Function** is a Proxy Agent that shall be able:

- to manage signalling over Gmb reference point between GGSNs and other BM-SC sub-functions, e.g. the BM-SC Membership Function and the BM-SC Session and Transmission Function;
- to handle when BM-SC functions for different MBMS services are provided by multiple physical network elements; routing of the different signalling interactions shall be transparent to the GGSN;
- to generate charging records for content provider charging of transmitted data. Content provider name is provided to BM-SC Proxy and Transport function over Gmb at session start.

The BM-SC Proxy and Transport function may act as an intermediate device for the MBMS data sent from the BM-SC Session and Transmission function to the GGSN. The Proxy and Transport Function may be divided further into a Proxy function managing the control plane (Gmb) and a Transport function managing the multicast payload.
The Proxy and Transport Function is an MBMS bearer service function.

The **BM-SC Membership function** shall be able :

- to provide authorization for UEs requesting to activate an MBMS service;
- to have subscription data of MBMS service users;
- to generate charging records for MBMS service users.

The Membership Function is an MBMS bearer service level function, but it may also provide user service level functions e.g. membership management etc. In this case it does also have a Gi interface.
MBMS user services may use the **Security functions** for integrity and/or confidentiality protection of MBMS data. The MBMS Security function is used for distributing MBMS keys (Key Distribution Function) to authorized UEs[2].

4.3.2 User Equipment

The UE shall support functions for the activation/deactivation of the MBMS bearer service and security functions as appropriate for MBMS.
The UE should, depending on terminal capabilities, be able to receive MBMS user service announcements, paging information (non MBMS specific) and support simultaneous services (for example the user can originate or receive a call or send and receive messages while receiving MBMS video content). Moreover the MBMS user service should be able to

2 *Detailed description of the security functions is provided in 3GPP TS 33.246.*

cope with losses in the MBMS data reception occurring in case of contemporary arrive of data and paging or announcements.
The UE shall be able to synchronize with the SGSN which MBMS UE contexts are still active.
Depending upon terminal capability, UEs may be able to store MBMS data The MBMS Session Identifier contained in the notification to the UE shall enable the UE to decide whether it needs to ignore the forthcoming transmission of MBMS session (e.g. because the UE has already received this MBMS session).

4.3.3 UTRAN/GERAN

UTRAN/GERAN are responsible for efficiently delivering MBMS data to the designated MBMS service area, they are both Radio Access Networks (RAN) for the MBMS architecture.
The UTRAN/GERAN shall :

- support mechanisms for efficient delivery of MBMS data in multicast mode, e.g. the number of users within a cell prior to and during MBMS transmission could be used to choose an appropriate radio bearer;
- support the initiation and termination of MBMS transmissions by the core-network, taking into account that MBMS transmissions may be initiated and terminated intermittently ;
- be able to receive MBMS data from the core-network over Iu bearers shared by many UEs;
- support both intra-RNC/BSC and inter-RNC/BSC mobility of MBMS receivers. Mobility is expected to cause limited data loss. Therefore, MBMS user services should be able to cope with potential data loss caused by UE mobility;
- be able to transmit MBMS user service announcements, paging information (non MBMS specific) and support other services in parallel with MBMS (for example depending on terminal capabilities the user could originate or receive a call or send and receive messages while receiving MBMS video content).

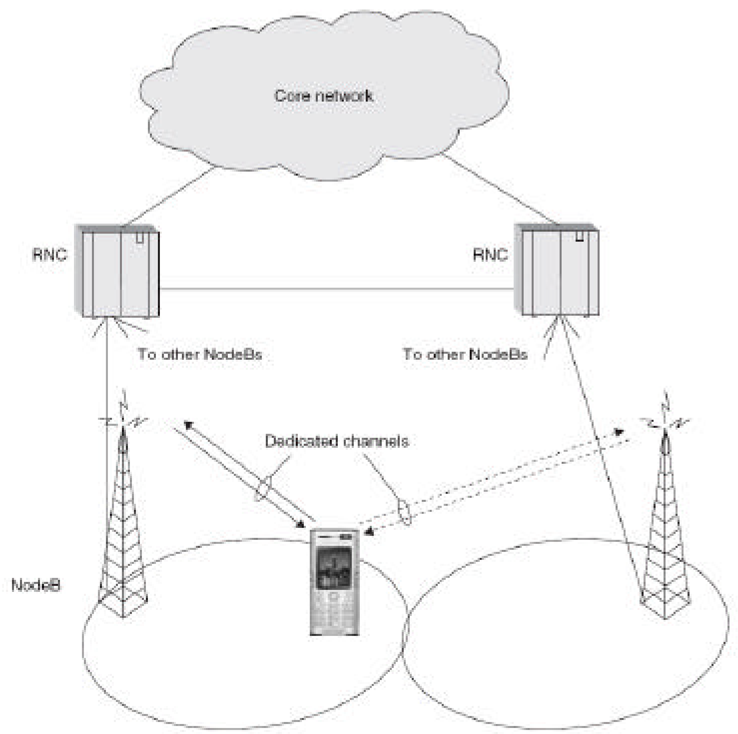

Figure 4.6 : UTRAN structure

4.3.4 SGSN

The SGSN's role within the MBMS architecture is to perform MBMS bearer service control functions for each individual UE and to provide MBMS transmissions to UTRAN/GERAN. The SGSN shall:

- provide support for intra-SGSN and inter-SGSN mobility procedures. Specifically this requires the SGSN to store a user-specific MBMS UE context for each activated multicast MBMS bearer service and to pass these contexts to the new SGSN during inter-SGSN mobility procedures;
- be able to indicate its MBMS support to the UE as well as it shall be able to synchronize with the UE, which of the UE's MBMS UE contexts are still active;
- be able to generate charging data per multicast MBMS bearer service for each user. The SGSN does not perform on-line charging for either the MBMS bearer service or the MBMS user service (this is handled in the BM-SC);
- be able to establish Iu and Gn bearers shared by many users upon receiving a session start from the GGSN. Likewise, the SGSN shall be able to tear down these bearers upon instruction from the GGSN.

4.3.5 GGSN

The GGSN role within the MBMS architecture is to serve as an entry point for IP multicast traffic as MBMS data.

The GGSN shall:

- be able to request the establishment of a bearer plane for a broadcast or multicast MBMS transmission upon notification from the BM-SC;
- be able to tear down the established bearer plane upon BM-SC notification. Bearer plane establishment for multicast services is carried out towards those SGSNs that have requested to receive transmissions for the specific multicast MBMS bearer service;
- be able to receive MBMS specific IP multicast traffic and to route this data to the proper GTP tunnels set-up as part of the MBMS bearer service;
- provide features that support the MBMS bearer service and are not exclusive to MBMS. Examples are Message Screening (not needed if the MBMS sources are internal in the PLMN), Charging Data Collection and Flow Based Charging[3].

4.3.6 MBMS Data Sources and Content Provider

The reference point from the content provider to the BM-SC is not standardized by 3GPP [6].

4.3.7 Other Functional Element CBC

The Cell Broadcast Centre (CBC) may be used to announce MBMS user services to the users.

4.4 MBMS channels

In UTRA the data generated at higher layers is carried over the air with transport channels, which are mapped in the physical layer to different physical channels.

One requirement in the design of MBMS was to reuse existing channels to the extent possible [1]. Therefore, the FACH transport channel and the S-CCPCH physical channel

3 See T S 23.246 V7.4.0 section 10.

are reused without any changes. To carry the relevant MBMS data and signaling, three new logical channels are added to Release 6:

- MBMS Traffic Channel (MTCH), carrying application data.
- MBMS Control Channel (MCCH), carrying control signaling.
- MBMS Scheduling Channel (MSCH), carrying scheduling information to support discontinuous reception in the UE.

As shown in Figure 4.7, all these channels use FACH as the transport channel type and the S-CCPCH as the physical channel type. In addition to the three new logical channels, one new physical channel, MBMS Indicator Channel (MICH), is introduced to support MBMS. MICH used to notify the UE about an upcoming change in MCCH contents.

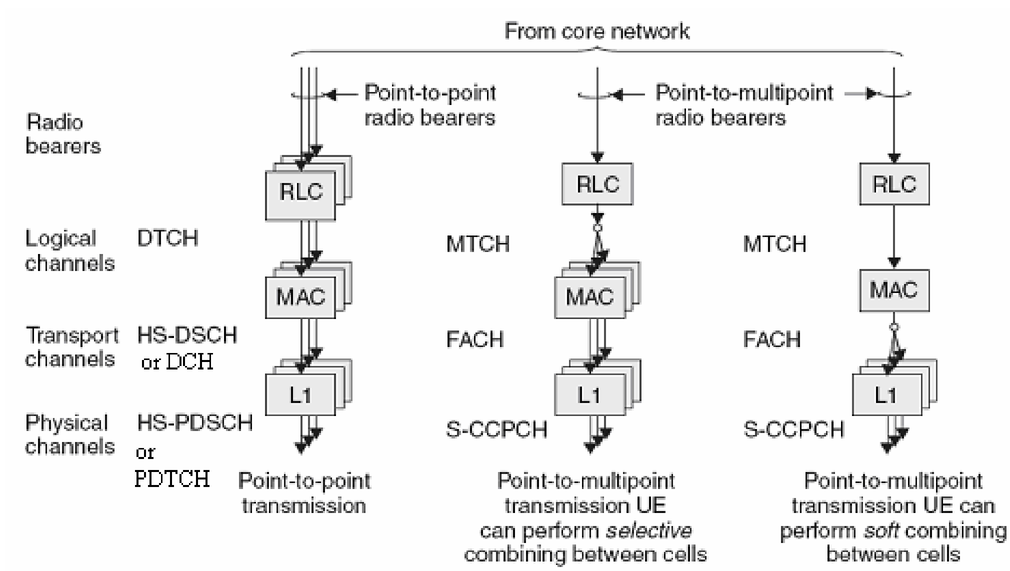

Figure 4.7: MBMS Channels Mapping

4.4.1 MTCH

The MTCH is the logical channel used to carry the application data in case of point-to-multipoint transmission (for point-to-point transmission, DTCH, mapped to DCH or HS-DSCH, is used). One MTCH is configured for each MBMS service and each MTCH is mapped to one FACH transport channel. The S-CCPCH is the physical channel used to carry one (or several) FACH transport channels. The RLC for MTCH is configured to use unacknowledged mode as no RLC status reports can be used in point-to-multipoint transmissions. To support selective combining, the RLC has been enhanced with support for in-sequence delivery using the RLC PDU sequence numbers. This enables the UE to do reordering up to a depth set by the RLC PDU sequence number space in case of selection combining. The leftmost part of the Figure 4.7 illustrates the case of point-to-point transmission, while the middle and rightmost parts illustrate the case of point-to-multipoint transmission using the MTCH. In the middle part, one RLC entity is used with multiple MAC entities. This illustrates a typical situation where selection combining is used, where multiple cells are loosely time aligned and the same data may be transmitted several TTIs apart in the different cells. Finally, the rightmost part of the figure illustrates a typical case where soft combining can be used. A single RLC and MAC entity is used for transmission in multiple cells. To allow soft combining, transmissions from the different cells need to be aligned within 80. 67 ms (assuming 80 ms TTI).

4.4.2 MCCH and MICH

The MCCH is a logical channel type used to send control signaling necessary for MTCH reception. One MCCH is used in each MBMS-capable cell and it can carry control information for multiple MTCHs. The MCCH is mapped to FACH (note, a different FACH than used for MTCH), which in turn is transmitted on an S-CCPCH physical channel. The same S-CCPCH as for the MTCH may be used, but if soft combining is allowed for MTCH, different S-CCPCHs for MTCH and MCCH should be used The reason for using separate S-CCPCHs in this case is that no selection or soft combining is used for the MCCH, and the UE receives the MCCH from a single cell only. The RLC is operated in unacknowledged mode for MCCH. Where to find the MCCH is announced on the BCCH (the BCCH is the logical channel used to broadcast system configuration information). Transmission on the MCCH follows a fixed schedule as illustrated in Figure 4.8.

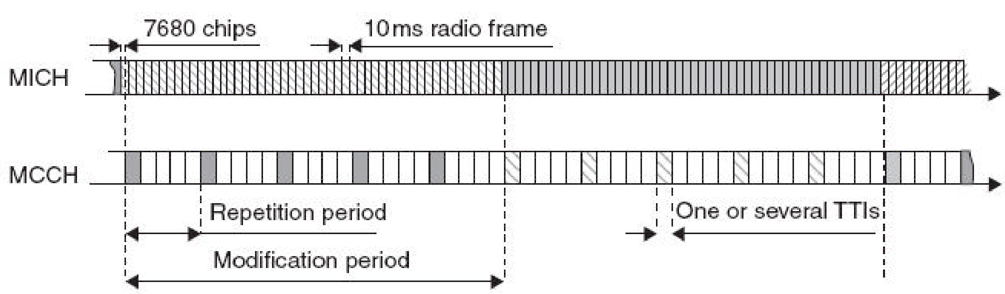

Figure 4.8: MCCH transmission schedule

The MCCH information is transmitted using a variable number of consecutive TTIs. In each modification period, the critical information remains unchanged[4] and is periodically transmitted based on a repetition period. This is useful to support mobility between cells; a UE entering a new cell or a UE who missed the first transmission does not have to wait until the start of a new modification period to receive the MCCH information. The MCCH information includes information about the services offered in the modification period and how the MTCHs in the cell are multiplexed. It also contains information about the MTCH

4 The MBMS access information may change during a modification period, while the other MCCH information is considered as critical and only may change at the start of a modification period.

configuration in the neighboring cells to support soft or selective combining of multiple transmissions. Finally, it may also contain information to control the feedback from the UEs in case counting is used.

Counting is a mechanism where UEs connect to the network to indicate whether they are interested in a particular service or not and is useful to determine the best transmission mechanism for a given service. For example, if only a small number of users in a cell are interested in a particular service, point-to-point transmission may be preferable over point-to-multipoint transmission. To avoid the system being heavily loaded in the uplink as a result of counting responses, only a fraction of the UEs transmit the counting information to the network. The MCCH counting information controls the probability with which a UE connects to the network to transmit counting information. Counting can thus provide the operator with valuable feedback on where and when a particular service is popular, a benefit typically not available in traditional broadcast networks.

To reduce UE power consumption and avoid having the UE constantly receiving the MCCH, a new physical channel, the MICH (MBMS Indicator Channel), is introduced to support MBMS. Its purpose is to inform UEs about upcoming changes in the critical MCCH information and the structure is identical to the paging indicator channel. In each 10 ms radio frame, 18, 36, 72, or 144 MBMS indicators can be transmitted, where an indicator is a single bit, transmitted using on–off keying and related to a specific group of services. By exploiting the presence of the MICH, UEs can sleep and briefly wake up at predefined time intervals to check whether an MBMS indicator is transmitted. If the UE detects an MBMS indicator for a service of interest, it reads the MCCH to find the relevant control information, for example when the service will be transmitted on the MTCH. If no relevant MBMS indicator is detected, the UE may sleep until the next MICH occasion.

4.4.3 MSCH

The purpose of the MSCH is to enable UEs to perform discontinuous reception of the MTCH. Its content informs the UE in which TTIs a specific service will be transmitted. One MSCH is transmitted in each S-CCPCH carrying the MTCH and the MSCH content is relevant for a certain service and a certain S-CCPCH.

4.5 MBMS Protocols

4.5.1 User Plane Protocol Stack

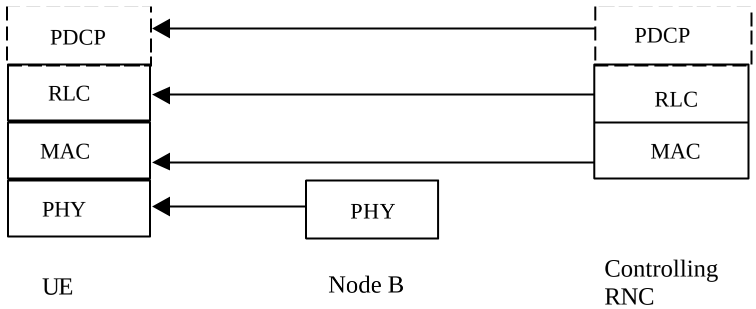

Figure 4.7: User Plane Protocol Stack

Figure 4.7 shows the User Plane Protocol Stack in UTRAN. PDCP sub-layer performs header compression/decompression for the MBMS traffic. In the UTRAN side, there is one PDCP entity per cell supporting MBMS or MBMS Cell Group for each MBMS service in each RNS. The shared PDCP entity in the UTRAN duplicates all PDCP PDUs to every RLC entity for every cell belonging to one MBMS Cell Group. In the UTRAN, there is one RLC entity for each MBMS service in each cell or cell group in case of utilization of selective combining or maximum ratio combining in TDD, and one MAC entity for each cell.
In the UE side, there is one PDCP and RLC entity for each MBMS service in each UE. In each UE there is one MAC entity per received cell when UE is performing the selective combining between these cells.
In case of P-t-P transmission, DTCH is used for MBMS transmission and the protocol termination for DTCH mapped on DCH and RACH/FACH.

4.5.2 Control Plane Protocol Stack

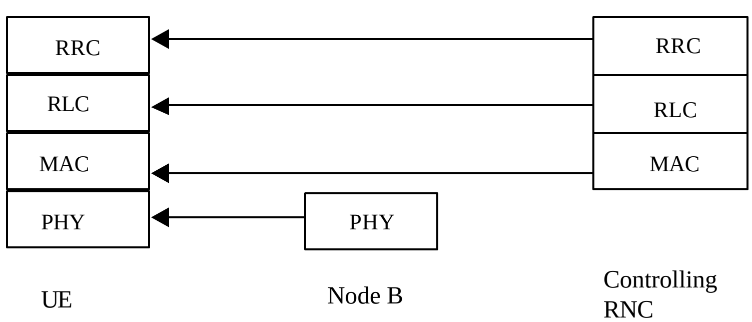

Figure 4.8 : Control Plane Protocol Stack

Figure 4.8 illustrates the protocol termination for MCCH in MBMS, which is P-t-M control channel.
MBMS functionalities are included in MAC and RRC.
In case of P-t-P transmission, DCCH is used for MBMS and the protocol termination for DCCH mapped on DCH and FACH.

4.5.3 UTRAN MAC Architecture to Support MBMS

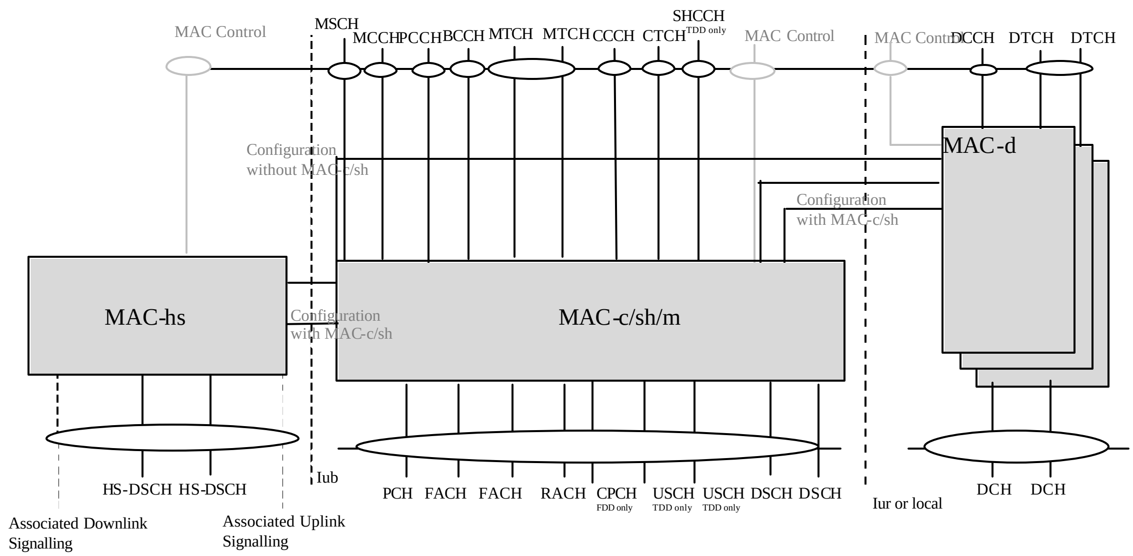

Figure 4.9: UTRAN MAC Architecture to Support MBMS

To support MBMS user and control plane transmission, a multicast functionality is added in the MAC c/sh, entitled "MAC m", to take care of scheduling of MBMS related transport channels as presented in Figure 4.9. MAC-c/sh/m is located in the RNC. The following functionalities are covered:

- Scheduling / Buffering / Priority Handling: This function manages common transport resources between MBMS and non-MBMS data flow(s) according to their priority and delay requirements set by higher layers.
- Addition of MBMS-ID: For p-t-m type of logical channels, the MBMS-ID field in the MAC header is used to distinguish between MBMS services.
- TFC selection: Transport format combination selection is done for a common transport channel (FACH) mapped to MTCH, MSCH and MCCH. In the case of MBMS soft combining, the combinable S-CCPCHs shall have the same TFC during the TTIs in which L1 combining is used

There is one MAC-c/sh/m entity in the UTRAN for each cell [5].

4.6 MBMS over HSPA

As S-CCPCH lacks of power control it would seem feasible to provide p-t-m transmission over HSDPA as it supports flexible link adaptation methods. Usage of HSDPA for p-t-m MBMS delivery could be useful from link efficiency point of view as well as it would give flexibility to allocate capacity between MBMS and other services. In fact HSDPA includes fast link adaptation and therefore can provide good link performance. Since separate radio resources are needed for each MBMS User Equipment (UE), the required Node B transmission resource allocation depends linearly on the number of active MBMS users per cell. Therefore P-t-P HSDPA solution is a suitable solution for MBMS service delivery for a limited amount of users requesting the same service. When the amount of users increases it is more efficient to use P-t-M MBMS transmission using Forward Access Channel (FACH). However in 3GPP Release 6, P-t-M MBMS solution suffers from moderate link performance due to lack of link adaptation, although link performance can be improved with advanced UE receivers (e.g. UE receive diversity). Macro diversity with soft or selective combining at UE is needed to ensure continuous coverage over whole cell area with MBMS service bit rates (e.g. 128 kbps). On the other hand, reserving transmission capacity in a fixed manner from all cells for a MBMS service may lead to inefficient use of radio resources if there are no active MBMS users in all cells. MBMS services can be also used for local area information such as traffic announcements, local news or weather reports, when the local area could be even a single cell. In this kind of scenario, reservation of transmission capacity over multiple cells would lead clearly to poor use of radio resources. A better approach would be to use single cell transmission either with a p-t-m (if there are several users requesting the same service) or P-t-P transmission mode (if there are only few users requesting the same service). One possibility to introduce more flexibility to MBMS is to extend HSDPA use for MBMS. In P-t-M MBMS over HSDPA scheme the same HS-PDSCH connection is shared by multiple users while still maintaining HS-PDSCH link features, like link adaptation with Adaptive Modulation Coding (AMC) and H-ARQ. However, these features were defined for HSDPA unicast service and there may incur some efficiency loss due to UEs experiencing different levels of fading when using P-t-M transmission mode. Without any link adaptation there are different parameters to be set in case of HSDPA usage for p-t-m transmission. Depending on selected Transport Format and Resource Combination (TFRC), which defines transport block size, number of used multi-codes and modulation, the number of transmissions should also be defined. UE reported Channel Quality Indicator (CQI) can be used for the link adaptation, although it is not well suited for streaming traffic with constant bit rate. In addition to CQI UE also reports Acknowledgments (ACK) and Negative Acknowledgments (NACK) for Layer 1 transport blocks [4].

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[3] 3GPP TR 23.246 V7.4.0 Technical Specification Group Services and System Aspects; Multimedia Broadcast/Multicast Service; Architecture and functional description (Release 7), available on www.3gpp.org.

[4] Point-to-Multipoint Multimedia Broadcast Multicast Service (MBMS) performance over HSDPA – Ville Vartiainen and Janne Kurjenniemi – 2007

[5] 3GPP TR 25.346 V7.7.0 Technical Specification Group Radio Access Network; Introduction of the Multimedia Broadcast Multicast Service (MBMS) in the Radio Access Network (Release 7), available on www.3gpp.org.

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Chapter 5
Implementation and Validation

5.1 Introduction

The implementation of the model to simulate the transmission power nedded for DCH, FACH and HS-DSCH are presented in this chapter. Actually the aim of the simulations is to find the threshold to switch between the different channel. The simulations are made by means of MATLAB. MATLAB is a numerical computing environment and programming language. Created by The MathWorks, MATLAB allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. Typical uses include:

- Math and computation
- Algorithm development
- Data acquisition
- Modelling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar not interactive language such as C [1].

This Chapter is organized as follows: first in section 5.2 DCH Transmission Power is explained, then in section 5.3 FACH Transmission Power, in section 5.4 HS-DSCH Transmission Power, then the considered macrocell environment is presented in section 5.5 and in section 5.6 the final code for the simulations is shown. Finally the validation is mentioned in section 5.7.

5.2 DCH Transmission Power

The Radio Network Controller (RNC) for radio efficiency reasons, can use both dedicated resources (one DCH for each UE in the cell) and common resources (one FACH for all the UEs) or shared resources (one HS-DSCH shared by all UEs in a cell) to distribute the same content in a cell. The total downlink transmission power allocated for all MBMS users in a cell that are served by multiple DCHs is variable. It mainly depends on the number of UEs, their location (close to the Node B or at cell edge) in the cell, the required bit rate of the MBMS session and the experienced signal quality Eb/No[1] for each user. In fact, all the users share the common bandwidth and each new connection increases the interference level of other connections. Equation 5.1 calculates the Node B's total transmission power required

1 Eb/No means simply bit energy divided by noise spectral density.

for the transmission of the data to ‘n’ users in a specific cell [2] and can be applied both in macro and micro cell environments.

$$P_T = \frac{P_P + \sum_{i=1}^{n} \frac{(P_N + x_i)}{\frac{W}{\left(E_b/N_0\right)_i R_{b,i}} + p} L_{p,i}}{1 - \sum_{i=1}^{n} \frac{p}{\frac{W}{\left(E_b/N_0\right)_i R_{b,i}} + p}}$$

Equation 5.1: DCH Transmission Power

where P_T is the base station total transmitted power, P_P is the power devoted to common control channels, $L_{p,i}$ is the path loss, $R_{b,i}$ the i-th user transmission rate, W the bandwidth, P_N the background noise, p is the orthogonality factor (p = 0 for perfect orthogonality) denoted also as 1-a and x_i is the intercell interference observed by the i-th user given as a function of the transmitted power by the neighboring cells P_{Tj}, j=1,…K and the path loss from this user to the j-th cell L_{ij}. More specifically [2] (Equation 5.2):

$$x_i = \sum_{j=1}^{k} \frac{P_{Tj}}{L_{ij}}$$

Equation 5. 2: InterCell Interference

The MATLAB code which implements the formula to calculate the DCH’s power can be found in Annex 1. Follows it is depicted the pseudo-code which calculates the DCH transmission power for N Users. The code implements the sum of the DCH transmission power for each user, considering intercell interference.

```
function PT=BSPtDCH(Pp , UsersRb, UsersCoordinate, NeigCellsPw, W, Pn, p, EbNoRatio)

%It calculates the BS Tx power to cover N users using DCH
%Pp = common control channels power, UsersRB = Bit Rate users vector,
%UsersCoordiante = users' coordinate vector, NeigCellsPw= neighbouring cells power vector
%W= bandwidth, Pn=thermal noise, p= orthogonality factor

%controls
for each user
      { if (User Coordinate more than cell radius)
            {'excessive distance';
             return;
            }
      }

if (Number of users different from the dimension of the bit rate vector)
```

```
      {'Number of Users different form the dimension of the Bit Rate
      vector';
       return;
      }

if (Dimension Number of neighbour cells different from 18)
      {'Not valid number of neighbour cells';
      return;
      }

if (Number of users different from the dimension of the Eb/No vector))
      {'Number of users different from the dimension of the Eb/No vector';
      return;
      }


% power calculation

for each user
      {Calculate intercell interference plus thermal noise;
       Calculate the Pathloss using distance from Node B to user;
       Calculate the ratio between Bandwidth and Eb/No·User bit rate
       plus orthogonality factor;
       N= common control channel power plus previous value plus intercell
       interference·Pathloss/ratio between bandwidth and Eb/No·user bit
       rate plus orthogonality factor;
       D= previous value plus orthogonality factor/ratio between bandwidth
       and Eb/No plus orthogonality factor;
      }
Power = N/(1-D);
return;
```

The following pseudo-code calculates the DCH transmission power to serve from 1 to N users. The code makes subgroup of users making growing vector of users coordinates, users Eb/No and users' bit rate. For each subgroup, the DCH transmission power id calculated by the previous function.

```
function PT=DCHTxPwNUsers(Pp , UsersRb, UsersCoordinate, NeigCellsPw, W,
Pn, p, EbNoRatio)

%it determinates the transmission power using of DCH to cover from 1 to N
%users
%Pp = common control channels power, UsersRB = Bit Rate users vector,
%UsersCoordiante = users' coordinate vector, NeigCellsPw= neighbouring
cells power vector
%W= bandwidth, Pn=thermal noise, p= orthogonality factor


%controls
for each user
      { if (User Coordinates more than cell radius)
            {'excessive distance';
             return;
            }
      }
```

```
if (Number of users different from the dimension of the bit rate vector)
      {'Number  of  Users  different  form  the  dimension  of  the  Bit  Rate
      vector';
       return;
      }

if (Dimension Number of neighbour cells different from 18)
      {'Not valid number of neighbour cells';
      return;
      }

if (Number of users different from the dimension of the Eb/No vector)
      {'Number of users different from the dimension of the Eb/No vector';
      return;
      }

%power calculation
for each subgroup of users
      {make vector of bit rate of the subgroup of users;
       make vector of coordinate of the subgroup of users;
       make vector of Eb/No of the subgroup of users;

       calculate the power of the subgroup of users by the function  which
       calculates the DCH transmission power for N users and store it in a
       vector;
       %this vector has the power for a growing number of users
      }

%result plot
plot the power for a growing number of users;

save results;

return;
```

The code which calculates the intercell interference, implements the sum of the received power transmitted by the neighbouring cells. The pseudo-code which implements the formula to calculate the intercell interference is the follows:

```
function xi=xiCalc(NeigCellsPw, UserCoordinate)

% it calculates the intercell interference observed by the i-th user using
the
% transmitted power by the neighbouring cells ‘NeigCellsPw’ and the path-
loss
%from this user to j-th cell. It uses a 18 neighbouring cells model

model the distribution of the cells by vector of coordinates of the cells;

% controls
if (dimension of the power cell vector different from 18)
      {'Error in intercell interference calculation';
       return;
```

```
      }

for each cell
      {calculate the intercell interference and plus previous value to the
       new value;
      }

return;
```

All the MATLAB code relative to this pseudo-code can be found in the Annex1;

5.3 FACH Transmission Power

A FACH channel essentially transmits at a fixed power level since fast power control is not supported in this channel. FACH is a point to multipoint (PtM) channel and must be received by all UEs throughout the cell. Consequently, the fixed power should be high enough to ensure the service in the whole coverage area of the cell and independently of UEs location [6]. The bit rate of the MBMS service and the desirable coverage area of the cell are factors that affect the allocated power for a FACH. FACH power efficiency strongly depends on maximizing diversity as power resources are limited. Diversity can be obtained by the use of a longer TTI in order to provide time diversity against fast fading (fortunately, MBMS services are not delay sensitive) and the use of combining transmissions from multiple cells to obtain macro diversity. A basic constraint is that the delivery of high data rate MBMS services over FACH is not feasible, since excessive downlink transmission power would be required (overcoming the maximum available base station power of 20W). High bit rates can only be offered with FACH to users located very close to Node B.

In [4] results are presented in terms of Ec/Ior [dB] representing the fraction of cell transmit power necessary to achieve the corresponding BLER performance graduated on the vertical axis. Another commonly used and related parameter is the geometry factor (G) defined as the ratio of the received interference power from the serving cell P_{own} divided by the received power from neighbouring cells P_{other}, or inter-cells interference x_i, plus thermal noise P_n, as shown in Equation 5.3.

$$G = \frac{P_{own}}{P_{other} + P_{noise}}$$

Equation 5.3: Geometry Factor

Examples of conversion of Ec/Ior [dB] to cell power fraction [%] form [4] are shown in Table 5.1.

Table 5. 1: Ec/Ior FACH % Transmission Power Mapping

Ec/Ior [dB]	%Tx	Ec/Ior [dB]	%Tx	Ec/Ior [dB]	%Tx
0.0	100.0%	-5.5	28.2%	-11.0	7.9%
-0.5	89.1%	-6.0	25.1%	-12.0	6.3%
-1.0	79.4%	-6.5	22.4%	-13.0	5.0%
-1.5	70.8%	-7.0	20.0%	-14.0	4.0%
-2.0	63.1%	-7.5	17.8%	-15.0	3.2%
-2.5	56.2%	-8.0	15.8%	-16.0	2.5%
-3.0	50.1%	-8.5	14.1%	-17.0	2.0%
-3.5	44.7%	-9.0	12.6%	-18.0	1.6%
-4.0	39.8%	-9.5	11.2%	-19.0	1.3%
-4.5	35.5%	-10.0	10.0%	-20.0	1.0%
-5.0	31.6%				

Figure 5.1, Figure 5.2 and Figure 5.3 from [4] show the S-CCPH power requirement as a fraction of the Node B power when transmitting at 16, 32, 64 and 128 kbps with various TTI values.

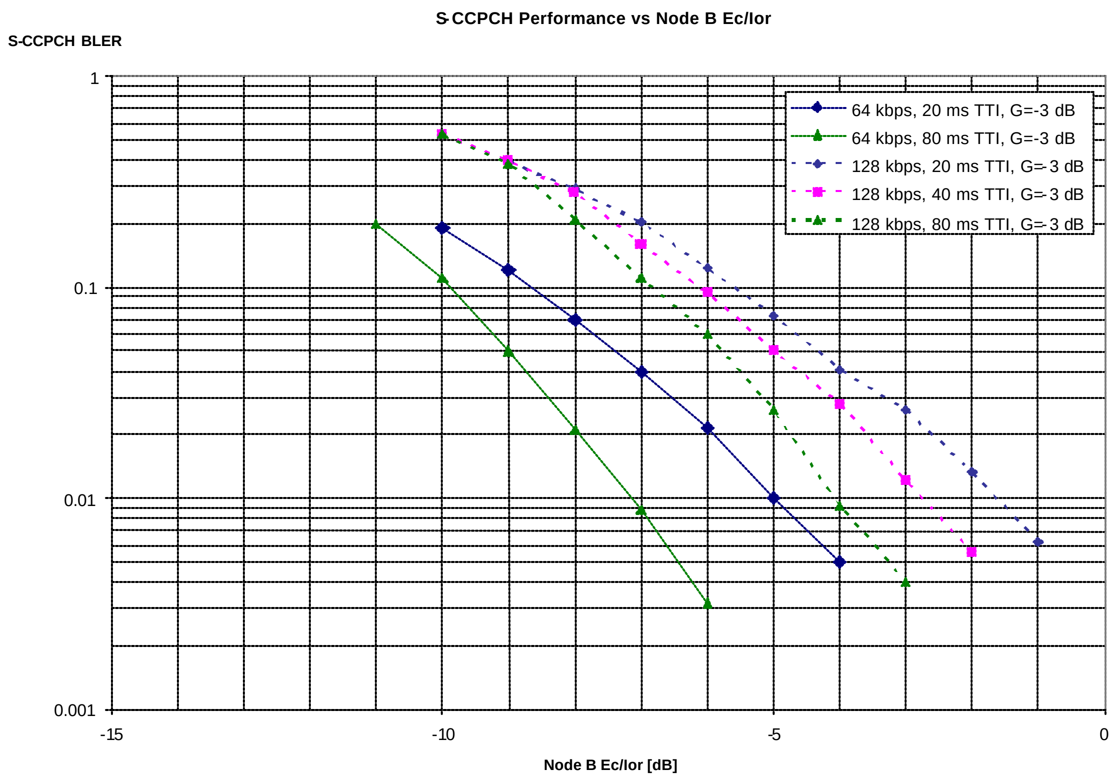

Figure 5. 1: S-CCPCH Power Requirement for G=-3 dB

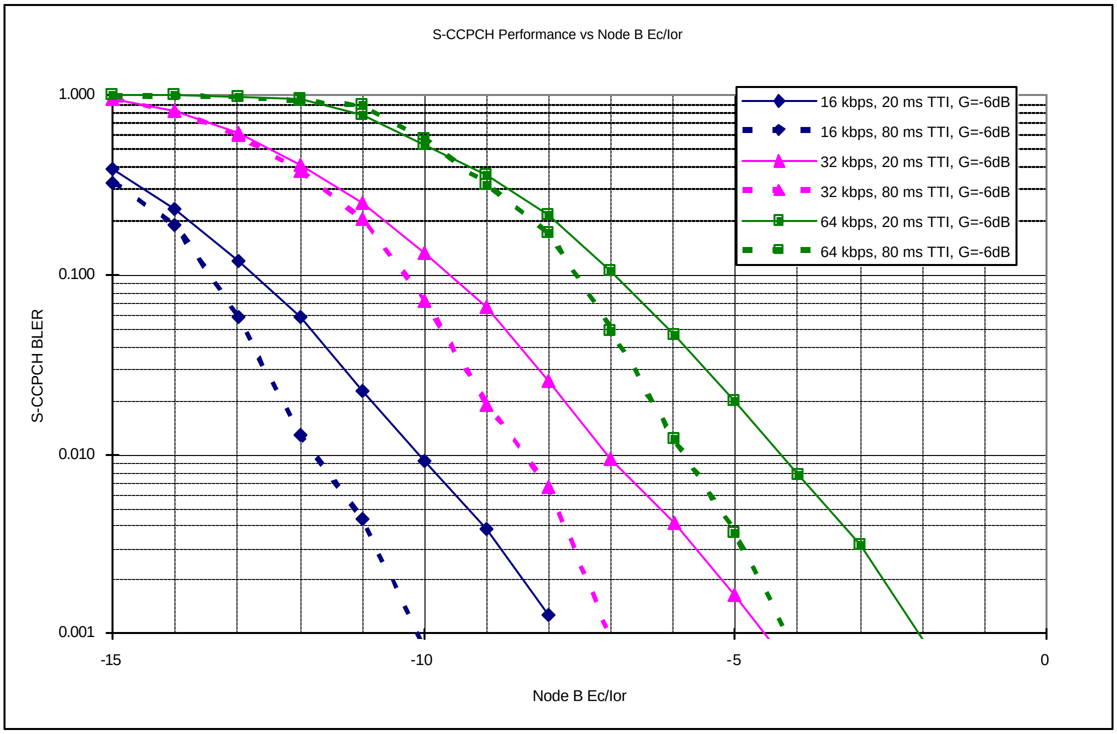

Figure5.2: S-CCPCH Power Requirement for G=-6 dB

Fixing the BLER, TTI, the geometry factor (G) and the Bit Rate is possible to calculate the percentage of Node B transmission power.

For example for BLER under 1%, 128 Kbps, TTI= 20 ms and G=-3 dB, the Ec/Ior [dB] obtained form Figure 5.1 is -1 dB, than the percentage of Node B transmission power is 79.4%. This means that for 20 W of Node B total transmission power, FACH needs 15.8 W.

Table 5.2 presents some indicative FACH downlink transmission power levels obtained for various percentages of cell radius and MBMS bit rates, without assuming diversity techniques [4]. Bit rate over 128 Kbps are not considered because the needed power is too high.

Table 5. 2: FACH Transmission Power

Cell Radius	Cell Coverage	MBMS Service Bit Rate (Kbps)	Required TX PW (W)
60 %	37 %	64	3
		128	6.4
80 %	64 %	64	4.8
		128	9.8
95 %	91 %	64	7.6
		128	15.8

5.4 HS-DSCH Transmission Power

HSDPA can work in two way: the first is that the allocated power for HS-DSCH is independently from the Node B transmission power allocated for the other channels and the second is that HS-DSCH can use only the remain power of the Node B. For example if the maximum Node B transmission power is 20W and for all other channels 13W are allocated, HS-DSCH can use 7W of Node B transmission power. The simulations are made using this second way.

The fundamental features of HSDPA link adaptation functionality are adaptive modulation[2] and coding (AMC), multicode transmission (multiple HS-PDSCHs), and fast hybrid automatic repeat request (HARQ). In this way HSDPA can adjust the data rate to the available channel quality.
To chose the Eb/No, corresponds uniquely to a certain Block Error Rate (BLER) for a given data rate where the only adaptation parameter is the spreading gain. However, the Eb/No metric is not an attractive measure for HSDPA because the bit rate on the HS-DSCH can be varied every transmission time interval (TTI) using different modulation schemes, effective code rates, and a number of HS-PDSCH codes. The common choice to work with HS-DSCH is to use the signal-to-interference-plus-noise ratio (SINR) which influences the BLER [8]. The average HS-DSCH SINR for a single-antenna Rake receiver is defined as in Equation 5.4:

$$SINR = SF_{16} \frac{P_{HS-DSCH}}{(1-a)\bullet P_{own} + P_{other} + P_{noise}}$$

Equation 5. 4: HS-DSCH SINR

where SF_{16} is the HS-PDSCH spreading factor of 16, $P_{HS-DSCH}$ is the received power of the HS-DSCH summing all active HS-PDSCH codes, P_{own} is the received own-cell interference, 1-a is the downlink orthogonality factor, P_{other} is the other-cells or intercells interference denoted also as x_i, and P_{noise} is the received noise power. In some 3GPP documents, own-cell interference is denoted I_{or} while intercells interference is expressed as I_{oc}. Note that the HS-DSCH SINR is independent of the number of HS-PDSCH codes used, the modulation scheme, and the effective code rate. The HS-DSCH SINR metric is an essential measure for HSDPA link budget planning and network dimensioning [8].

2 QPSK and 16QAM, 16QAM is used for high SINR

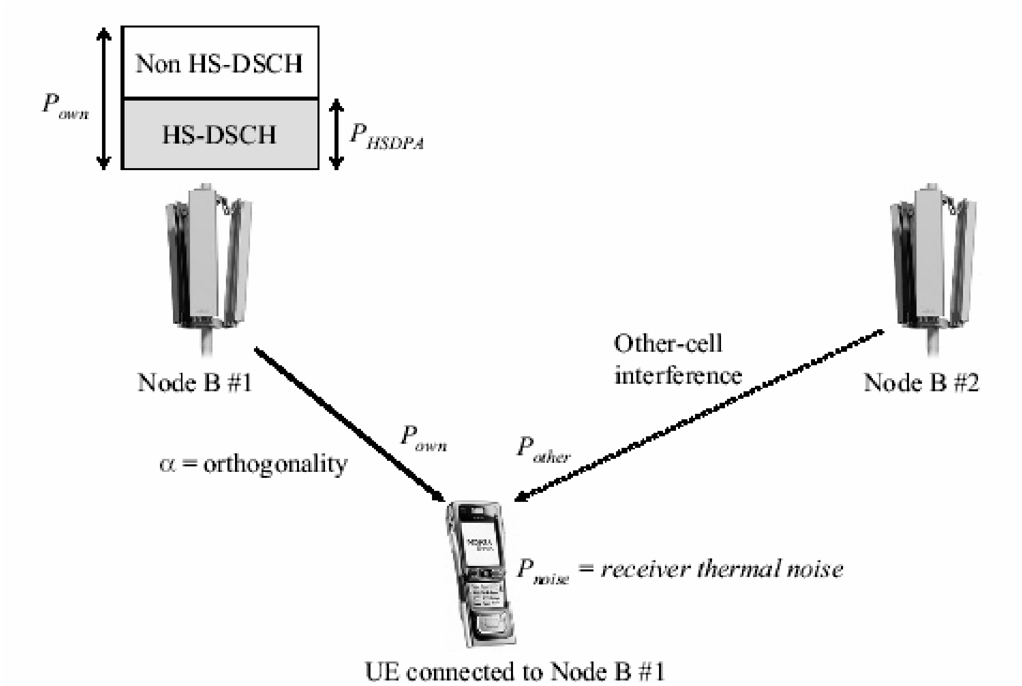

Figure 5. 2: Environment

Fixed the SINR and the percentage of cell radius by the G factor it is possible to calculate the needed power for HS-DSCH by the equation 5. 5:

$$P_{HS-DSCH} \geq SINR\left[1 - a + G^{-1}\right]\frac{P_{own}}{SF_{16}}$$

Equation 5.5: HS-DSCH Transmission Power

To obtain a good user experience, SINR should not be less than 21 dB or the BLER will be over the 10%. The following pseudo-code calculates SINR in function of the HS-DSCH transmission power and the distance, while the relative MATLAB code can be found in Annex1. SINR is calculated for each considered HS-DSCH transmission power level for distance from 0.100 Km to 0.577 Km.

```
function SINRHsdschPw(UserCoordinates, Pn, p, Pown, NeigBSPw, PwHsdsch)
%it calculates the SINRs in function of % of coverage and HS-DSCH power
%Pn= thermal noise power, p= orthogonality factor, NeigBSPw= Pother,
%PwHsdsh= HS-DSCH transmission power

%calculation
for each HS-DSCH transmission power level
    {for each distance
```

```
            {call the function which calculate the SINR [dB]
            }
    }

%results plot
plot each SINR for each power level in function of the distance;
figure;

return;
```

The follow ing pseudo-code implements the SINR formula and the relative MATLAB code can be found in Annex1.

```
function dBSINR=SINRdB(hs_dschtxpw, UserCoordinate, Pn, NeigBSPw, Pown, p)
%calculate the SINR in Db
%hs_dschtxpw= HS-DSCH transmission power, UserCoordinate= coordinate of
%the user, Pn=thermal noise power, NeigBSPw= vector of the power of the 18
%neighboring cells, p=orthogonality factor

calculate the Pathloss form the considered Node B and the user;

calculate the intercell interference from 18 neighbor cell;

calculate the SINR
      {multiply the HS-DSCH transmission power for a antenna gain of 11
      dB;
      calculate the HS-DSCH received power as ratio between the HS-DSCH
      transmission power and the pathloss from the considered Node B and
      the user;
      calculate the received intracell interference as ratio of Pown and
      the pathloss from the considered Node B and the user and multiply
      for the orthogonality factor;
      calculate the SINR multiply for the SF16 the HS-DSCH received power
      and dividing for the sum of thermal noise power plus the intercell
      interference plus the intracell interference;
      }

make SINR in linear;

return;
```

Fixing the value of SINR, the number of users that HS-DSCH can serve is in function of the maximum CQI value. The CQI value changes as shown in Figure 5. 4.

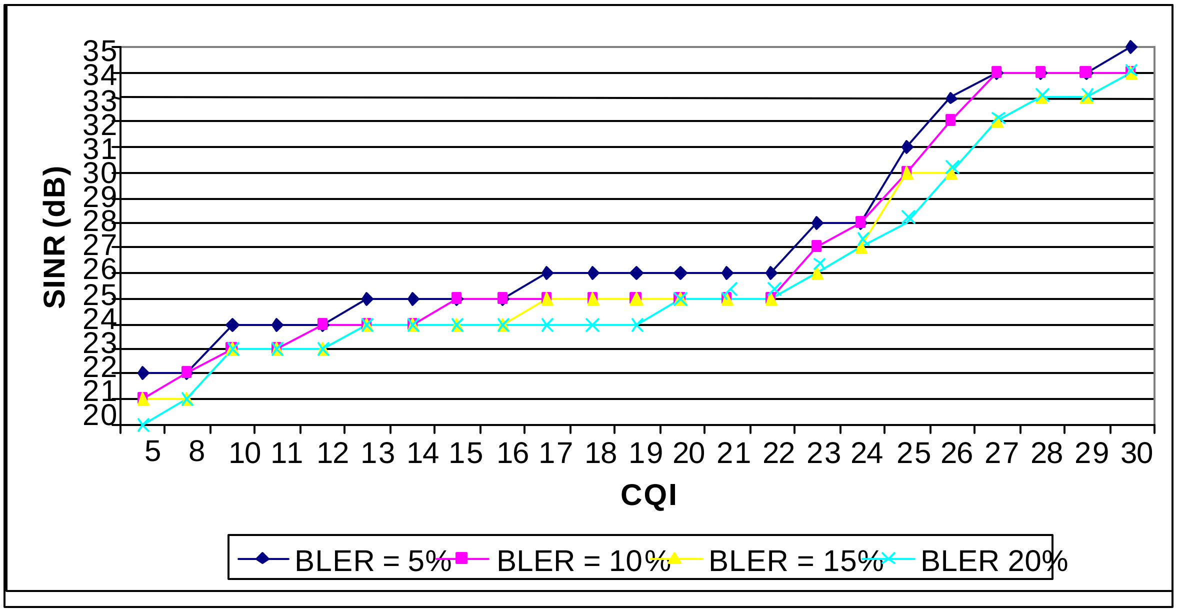

Figure 5.4: CQI SINR Link

Table 5. 3: HS-DSCH Parameter

CQI	modulation	#codes	TFRI	block size	RLC size	Num RBs
1	QPSK	1	0	137	320	0
2	QPSK	1	3	173	320	0
3	QPSK	1	8	233	320	0
4	QPSK	1	15	317	320	0
5	QPSK	1	20	377	320	1
6	QPSK	1	27	461	320	1
7	QPSK	2	4	650	320	1
8	QPSK	2	15	792	320	2
9	QPSK	2	24	931	320	2
10	QPSK	3	18	1262	320	3
11	QPSK	3	27	1483	320	4
12	QPSK	3	36	1742	320	5
13	QPSK	4	35	2279	320	6
14	QPSK	4	42	2583	320	7
15	QPSK	5	43	3319	320	9
16	16QAM	5	8	3565	320	10
17	16QAM	5	17	4189	320	12
18	16QAM	5	23	4664	320	13
19	16QAM	5	30	5287	320	15
20	16QAM	5	36	5887	320	17
21	16QAM	5	42	6554	320	19
22	16QAM	5	47	7168	320	21
23	16QAM	7	45	9719	320	28
24	16QAM	8	47	11418	320	33

25	16QAM	10	48	14411	320	42
26	16QAM	12	48	17548	320	52
27	16QAM	15	48	21754	320	64
28	16QAM	15	52	23370	320	69
29	16QAM	15	54	24222	320	72
30	16QAM	15	57	25558	320	76

As shown in Table 5.3, each CQI corresponds to a modulation and a number of orthogonal codes for physical channel. Considering the HSDPA TTI (2 ms) and packet dimension[3], the obtained bit rate of each channel for the two modulations are respectively 480 Kbit/s for QPSK and 960 Kbit/s for 16QAM. The total bit rate of the channel is calculated multiplying the number of the orthogonal code for the bit rate. Finally to calculate the users' number that is possible to serve using HS-DSCH is necessary to divide the final bit rate of the channel per the application bit rate.

5.5 Macrocell Environment

In this section, the topology deployment that has been used in the simulations is presented. Figure 5.5 shows the macro cell environment, which consists of 19 hexagonal cells. The model has been implemented considering the interested cell as origin of the reference system.

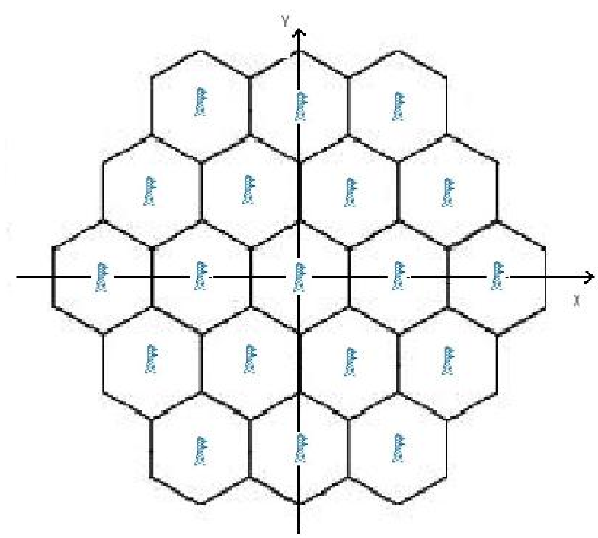

Figure 5.5: Macrocell Environment

3 After CRC, turbo coding, padding and segmentation

The MATLAB code which implements this model can be found in Annex1.

The simulations assumptions are presented in Table 5.4 [5], [6].

Table 5. 4: Simulation Parameter

Parameter	Value
Cellular layout	Hexagonal grid
Number of neighboring cells	18
Site to site distance	1 Km
Cell radius	0.577 Km
Maximum BS Tx power	20 W
Other BS Tx power	5 W
Common channel power	1 W
Orthogonality factor (0 : perfect orthogonality)	0.5
Eb/No target	5 dB

The distance used in these simulations are: 0.550 Km for 95% of cell radius, 0.460 Km for 80% of cell radius and 0.350 Km for 60% of cell radius. Respectively these values correspond to 91%, 64% and 37% of cell coverage.

For the simulations the data bit rate chosen are 64 Kbit/s, 128 Kbit/s and 256 Kbit/s [4].

5.5.1 Path Loss

The Okumura Hata's path loss model is employed. The general formula is shown in Equation 5.6.

$$L = 40\left(1-4\times10-3Dhb\right)Log_{10}\left(R\right)-18Log_{10}\left(Dhb\right)+21Log_{10}\left(f\right)+80 \qquad [dB]$$

Equation 5.6 Okumura Hata's Path Loss

Where:

- R is the base station - UE separation in kilometers;
- f is the carrier frequency of 2 GHz;
- Dhb is the base station antenna height, in meters, measured from the average rooftop level.

Considering a carrier frequency of 2 GHz and a base station antenna height of 15 meters (Dhb = 15 m), the formula becomes [3] (Equation 5.7):

$$L = 128.1+37.6+Log_{10}\left(R\right) \qquad [dB]$$

Equation 5.7: Path Loss

After L is calculated, log-normally distributed shadowing (LogF) with standard deviation of 10 dB should be added, so that the resulting pathloss is the following:

$$Pathloss\_macro = L + LogF$$

Equation 5.8: Path Loss plus Shadowing

The worst case corresponds to LogF=10 dB and this has been considered in the simulations.

The MATLAB code implemented can be found in Annex1 and the relative pseudo-code is the following:

```
function L=PathLoss(distance Km)
%calculate the pathloss from Okumura-Hata's model. It uses BS height of
15m
%and frequency of 2 GHz. The distance R has to be in Km

if (distance more than zero)
      {calculate the pathloss using Okumura-Hata model;
      }
else pathloss=Shadowing;

make the pathloss linear;
return;
```

To calculate the distance the following code has been implemented:

```
function D=Distance(Pint1,Point2)
%it calculates the distance between two point which have the coordinate
[x;y]

calculate the Euclidean distance between the two point;
return;
```

5.6 Final code

The following pseudo-code is relative to the MATLAB code used in each simulation. For each simulation the power for each channel has been calculated considering the number of users that must be served. The code makes growing subgroups of users from 1 to N users. Uniform distribution of the users has been considered. Each subgroup of user is made by a vector of coordinates, a vector of bit rate and a vector of Eb/No. For each subgroup, the DCH transmission power for each percentage of coverage has been calculated. The intercell interference has always been considered and has been calculated by the implemented function. The code prints the residual time.

```
function PowerDHF(Pp , UsersRb, UsersCoordinate95, NeigCellsPw, W, Pn, p,
EbNoRatio, all HS-DSCH transmission power, Fach Power 95%, Fach Power 80%,
Fach Power 60)

%it calculates the DCH, FACH and HS-DSCH Tx power

calculate the coordinates of the users for 80% cell radius;
calculate the coordinates of the users for 80% cell radius;

%controls
for each coordinate at 95% cell radius
    {if (coordinate greater than 0.577 Km)
     'incorrect user distance';
     return:
    }
}

for each coordinate at 80% cell radius
    {if (coordinate greater than 0.577 Km)
     'incorrect user distance';
     return:
    }
}

for each coordinate at 60% cell radius
    {if (coordinate greater than 0.577 Km)
     'incorrect user distance';
     return:
    }
}

Control that the dimension of the vector of the bit rate is the same of
the vector of coordinates;

if (number of neighbor cells different from 18)
      {'Not valid number of cells';
       return;
      }

%power calculation

for subgroup of user coordinate
      {calculate the needed time;
       make the subgroup of the bit rate of the users;
       make the subgroup of the coordinates of the users for 95%,  80% and
      60% of cell radius;
       make the subgroup of Eb/No;

      calculate the power for 95% cell radius calling the function
      implemented for the DCH transmission power for N users;
      calculate the power for 80% cell radius calling the function
      implemented for the DCH transmission power for N users;
      calculate the power for 60% cell radius calling the function
      implemented for the DCH transmission power for N users;
      make the vector of the HS-DSCH transmission power for each
      considered power;
      make the vector of the FACH power for 95% cell radius;
```

```
      make the vector of the FACH power for 80% cell radius;
      make the vector of the FACH power for 60% cell radius;

      show the residual time;
      }

save results;

%results plot
plot each trend of power for each channel and each percentage of cell
radius;

return;
```

5.7 Validation

In this section the correct functioning of the implemented MATLAB code is demonstrated.

For each proof the worst case has been considered. It means that the users are always considered uniformed distributed in the edge of the coverage and the shadowing factor to calculate the pathloss has always been considered equal to 10 dB.

To test the code which calculates the HS-DSCH SINR ten proofs have been made using the same input argument for each proof. The results obtained for each proof are always the same because always the worst case has been considered.

To test the code which calculates the DCH power ten proofs have been made using the same input argument for each proof. The results obtained for each proof are always the same and they are shown in Table 5.5 and Table 5.6

Table 5. 5: DCH Transmission Power Results

First proof

Users'Number	Power
1	1.1206
2	1.2477
3	1.9377
4	2.6672
5	3.2158
6	3.7976
7	4.416
8	5.0742
9	5.5091
10	5.974
11	6.4722
12	7.0074
13	7.4637

14	7.9566
15	8.4907
16	9.0713
17	9.6581
18	10.3009
19	11.0081
20	11.79

Table 5. 6: DCH Transmission Power Results

Tenth Proof

Users'Number	Power
1	1.1206
2	1.2477
3	1.9377
4	2.6672
5	3.2158
6	3.7976
7	4.416
8	5.0742
9	5.5091
10	5.974
11	6.4722
12	7.0074
13	7.4637
14	7.9566
15	8.4907
16	9.0713
17	9.6581
18	10.3009
19	11.0081
20	11.79

Each function of the code has been tested and the results obtained are always the same.

All the results obtained are consistent with the result in [5], [6] and [8]. As example it is depicted one graph (Figure 5.6) form [5] for 64Kbit/s and one graph obtained from the simulations (Figure 5.7). As possible to see the trends are consistent but there are more values of HS-DSCH transmission power because to evaluate the threshold all possible values of HS-DSCH transmission power have been considered.

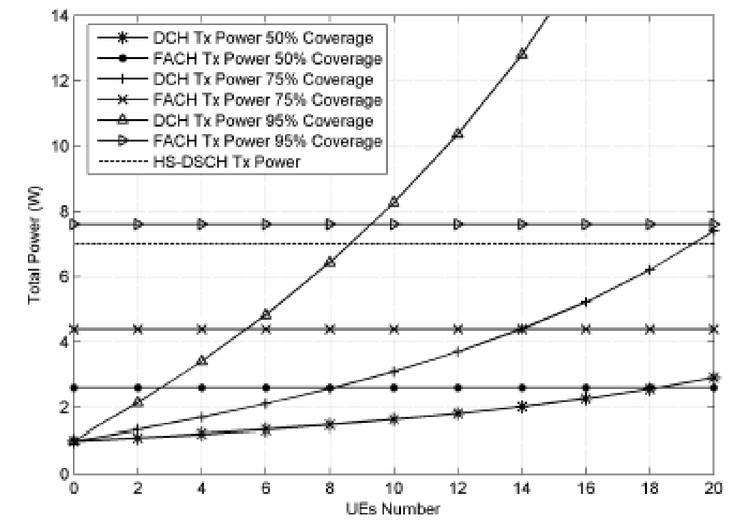

Figure 5.6: 64 Kbps Transmission Power from [5]

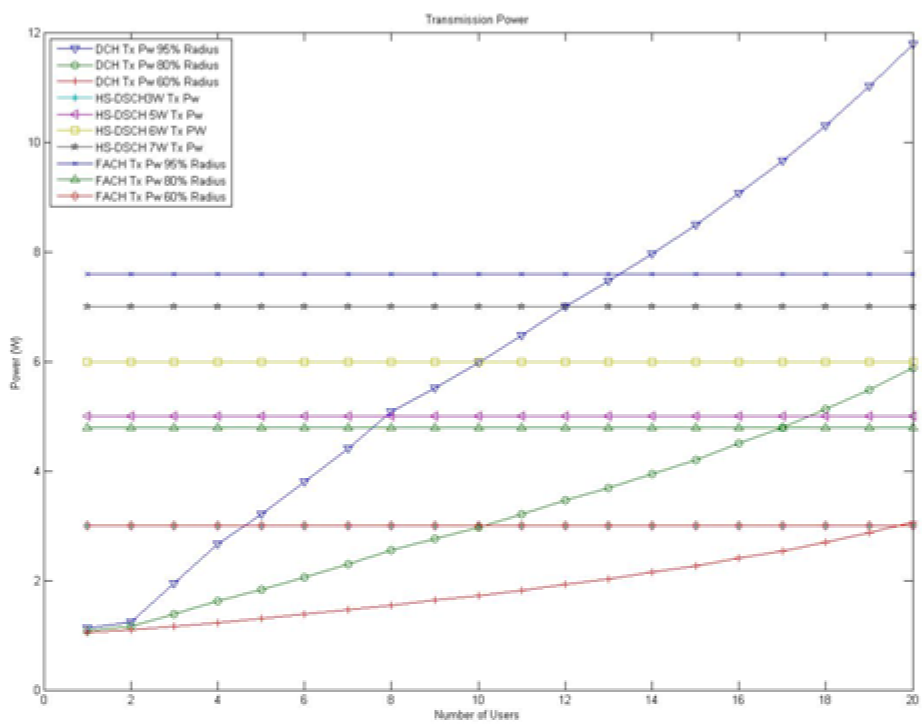

Figure 5.7 : 64 Kbps Transmission Power from simulation

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[8] Harri Holma, Antti Toskala – *HSDPA/HSUPA for UMTS – High Speed Radio Access for Mobile Communications* - 2006 John Wiley and Sons.

Chapter 6

Results

6.1 Introduction

In this chapter simulation results, obtained using the implemented MATLAB code, are presented. Transmission power levels when using DCH, FACH or HS-DSCH channels are depicted in each figure. The aim of this plotting is to determine the most efficient transport channel, in terms of power consumption for the transmission of the MBMS data. From the following figures is possible to see the fluctuation of transmission power of the Node B to vary simulation parameters in macro-cell environment. In each simulation it has been considered the worst case where all the users are uniformed distributed in the edge of the percentage of coverage. The users' distribution is depicted in Figure 6.1 and the MATLAB code which models that can be found in Annex.

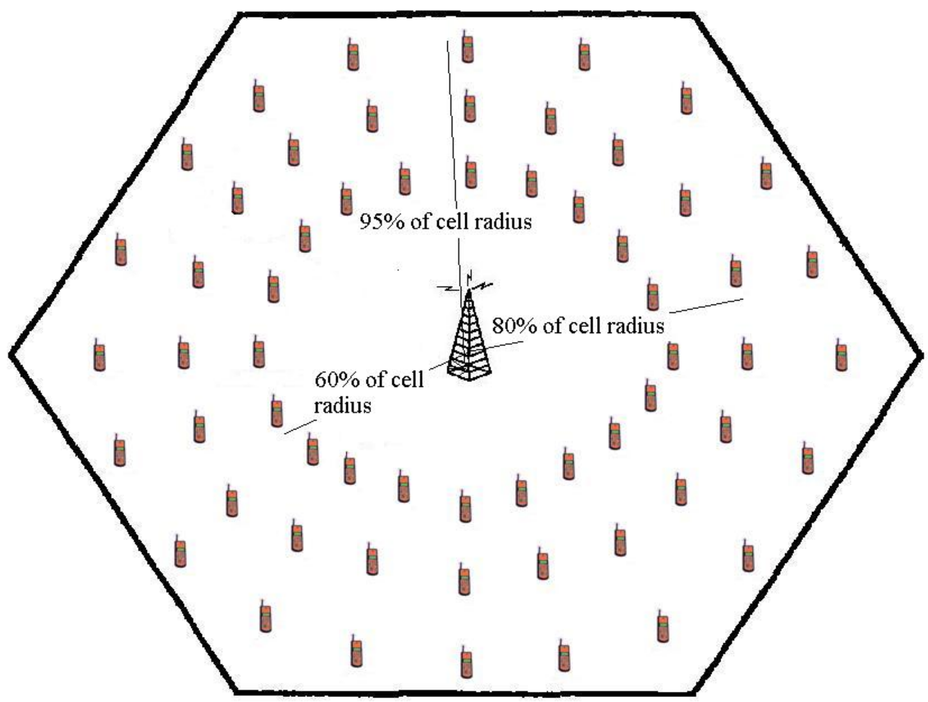

Figure 6.1: Users' Distribution

Before to evaluate the threshold for the power saving, it has been calculated the HS-DSCH SINR and the relative maximum number of users that can be served. These factors affect the HS-DSCH transmission power. Then several graphics are obtained for different bit rates and percentages of cell radius. The transport channel that requires less power resources is thus selected leading, in turn, to an advanced and resource economic MBMS delivery scheme. For the purpose of the evaluations, 64Kbps, 128Kbps and 256Kbps MBMS services for varying cell radius (60%, 80% and 95% of cell radius) are assumed. To know how many users want receive the MBMS service, it is assumed that the MBMS Counting is used by Node B [1].

This Chapter is organized as follows: first in Section 62 HS-DSCH SINR and Power are shown, then in Section 6.3 Switching Threshold for 64Kbps MBMS Application, in Section 6.4 Switching Threshold for 128Kbps MBMS Application, in Section 6.5 Switching Threshold for 256Kbps MBMS Application, next Section 6.6 shows the Threshold Comparisons in function of the cell radius and finally Section 6.7 shows a Coverage by Multiple Channels.

6.2 HS-DSCH SINR and Power

The first step is to fix the BLER target. From [4], [5], [6] and [7] BLER from 1% to 10% are considered form MBMS. Next from Figure 5.4 is possible to calculate the different CQI values for 21 to 34 SINR values showed in Table 6.1. If SINR is less than 21 it is not possible to achieve 10% of BLER, then only values from 21 dB are used.

Table 6.1: HS-DSCH Parameter

SINR	CQI	#Codes	Modulation	Single Channel's Bit Rate	Final Bit Rate [Kbps]
21	5	1	QPSK	480 Kbps	480
22	8	2	QPSK	480 Kbps	960
23	10	3	QPSK	480 Kbps	1440
	11	3	QPSK	480 Kbps	1440
24	12	3	QPSK	480 Kbps	1440
	13	4	QPSK	480 Kbps	1920
	14	4	QPSK	480 Kbps	1920
25	15	5	QPSK	480 Kbps	2400
	16	5	16QAM	960 Kbps	4800
	17	5	16QAM	960 Kbps	4800
	18	5	16QAM	960 Kbps	4800
	19	5	16QAM	960 Kbps	4800
	20	5	16QAM	960 Kbps	4800
	21	5	16QAM	960 Kbps	4800
	22	5	16QAM	960 Kbps	4800
27	23	7	16QAM	960 Kbps	6720
28	24	8	16QAM	960 Kbps	7680
30	25	10	16QAM	960 Kbps	9600
32	26	12	16QAM	960 Kbps	11520
34	27	15	16QAM	960 Kbps	14400
	28	15	16QAM	960 Kbps	14400
	29	15	16QAM	960 Kbps	14400
	30	15	16QAM	960 Kbps	14400

Using these results it has been obtained the Table 6.2 which shows the maximum number of users that is possible to serve using HS-DSCH for different SINR values. These values are obtained as follows. First, it is necessary to underline that the SINR value corresponds to a CQI value, the TTI for HS-DSCH is always 2 ms and that the data bit rate for each single channel (which is identified by an orthogonal code) is always 480Kbit/s if the QPSK modulation is used or 960Kbit/s if 16QAM modulation is used. These rates can be obtained considering that the dimension of the transport block size after the CRC (plus 24 bit), the Turbo coding (multiply for 3 and plus 12 bit) and the padding and segmentation, is 960 bit for QPSK and 1920 bit for 16QAM that sent in 2ms (TTI). In fact, dividing these 960 and 1920 to $2 \cdot 10^{-3}$ (ms), the data bit rates obtained are 480Kbit/s for QPSK and 960Kbit/s for 16QAM. Second, it is necessary to calculate the total data bit rate of HS-DSCH multiply the number of orthogonal code correspond to the CQI value to the corresponds single channel data bit rate. Finally, the users' number that can be served using HS-DSCH for each SINR value are calculated dividing the total data bit rate to the application bit rate.

Table 62: Maximum Users' Number

SINR [dB]	CQI	Users'Number 64Kbps	Users'Number 128Kbps	Users'Number 256Kbps
21	5	7	3	1
22	8	15	7	3
23	10	22	11	5
	11	22	11	5
24	12	22	11	5
	13	30	15	7
	14	30	15	7
25	15	37	18	9
	16	75	37	18
	17	75	37	18
	18	75	37	18
	19	75	37	18
	20	75	37	18
	21	75	37	18
	22	75	37	18
27	23	105	52	26
28	24	120	60	30
30	25	150	75	37
32	26	180	90	45
34	27	225	112	56
	28	225	112	56
	29	225	112	56
	30	225	112	56

Figure 6.2 shows SINR values in function of power and distance obtained by the implementation of the Equation 5.4. For example, if HSDPA transmission power is 7W, at 95% cell radius (0.550 Km) the SINR value is 23 dB. Using this value is possible to serve 22 users for 64 Kbps MBMS applications, 11 users for 128 Kbps MBMS applications and 5 users for 256 Kbps MBMS applications. To obtain the same SINR for 80% of cell radius must be used the same power, but for 60% of cell radius, 23 dB of SINR are also obtained using 6W. In this way, for 60% of cell radius is possible to serve the same number of users using less power or to obtain 24 dB of SINR. The last case means that more users can be

served. In fact, using 7W for 60% cell radius, the users that can be served are: 30 for 64 Kbps MBMS applications, 15 for 128 Kbps MBMS applications and 7 for 256 Kbps MBMS applications. To find the thresholds, all possible values of HS-DSCH have been considered. In this project, for each threshold, every HS-DSCH transmission power under the FACH transmission power has been evaluated. In fact, for each of these possible levels, it has been calculated the SINR and the relative number of user that can be served. These levels considered for HS-DSCH are from 3W to 16W because FACH transmission power levels are from 3W to 15.8W. Naturally, increasing the HS-DSCH transmission power, more users can be served. This process finds the best power allocation.

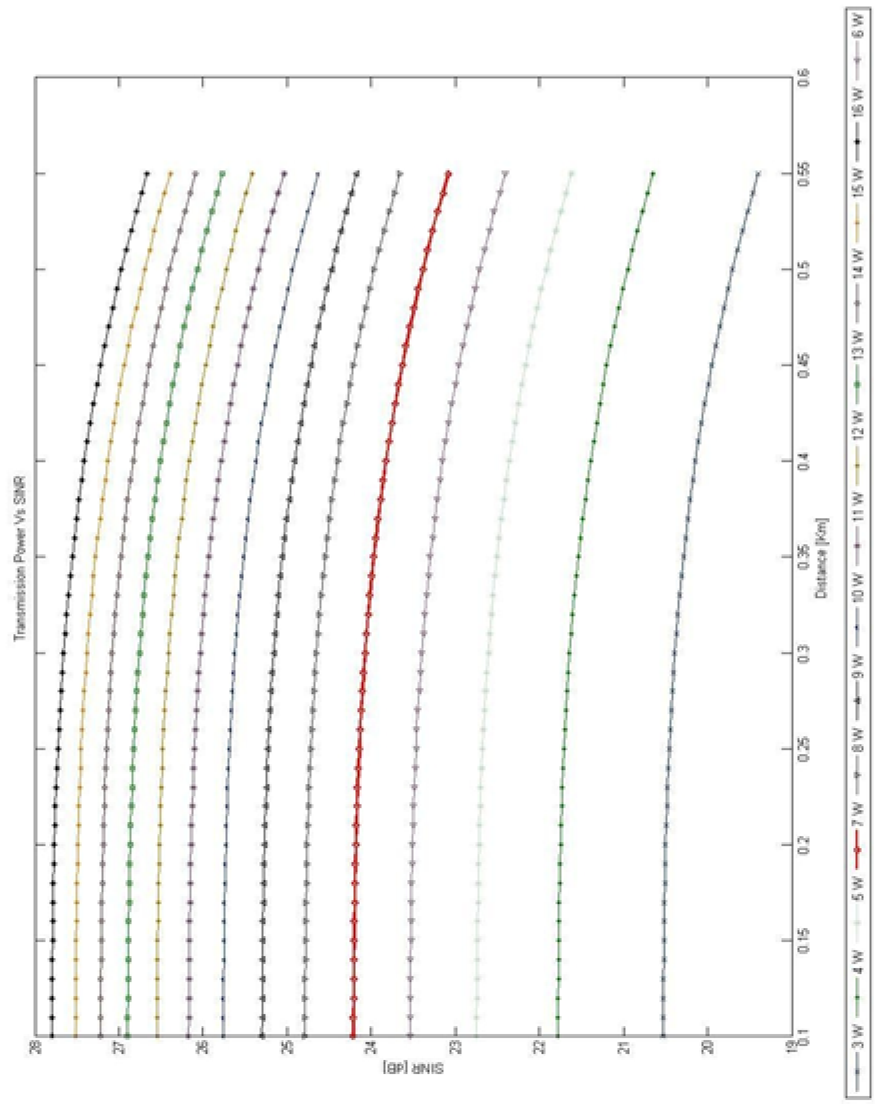

Figure 6.2: SINR Values in function of Power and Distance

6.3 Switching Thresholds for 64Kbps MBMS Applications

When multiple DCHs are used, from a certain number of users the power needed will be higher than the power of FACH or HS-DSCH. This means that over that number of users it is cheaper, in terms of power consumption, to cover using a common or a shared channel than a dedicated channel. The aim of this project is to find the thresholds, in terms of number of users, to switch from a dedicated channel to a shared or common channel. In Figure 6.3 the effect of increasing the number of users in the cell is presented for 64Kbps MBMS applications. The figure depicts how the switching points between DCHs and FACH or HS-DSCH change in function of the distance (or percentage of cell radius coverage) from the Node B. As expected, the switching threshold decreases increasing the distance.

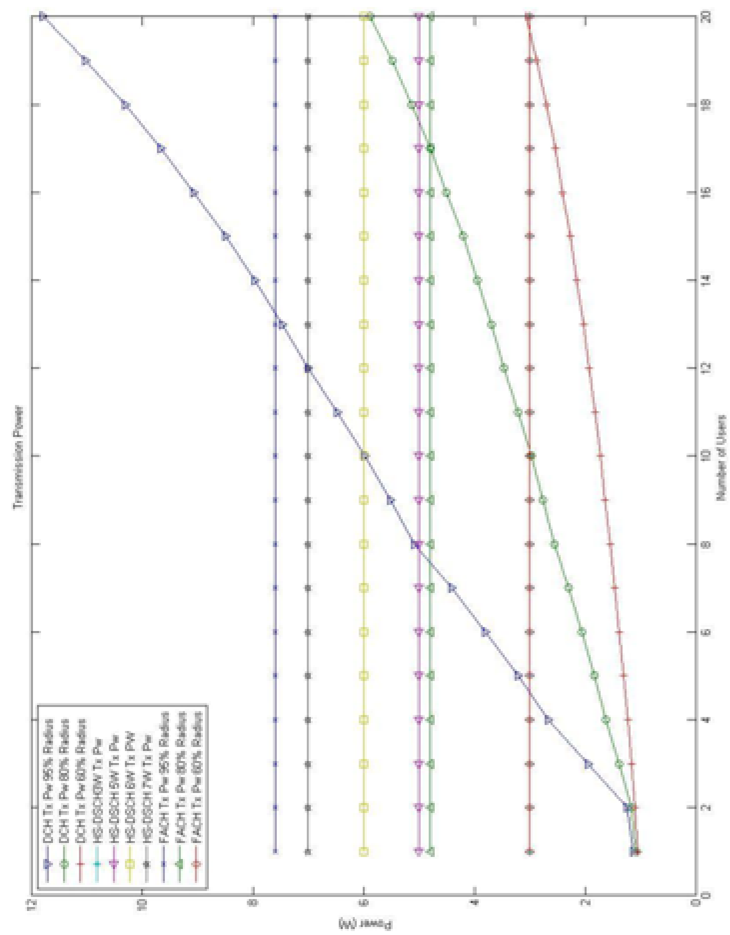

Figure 6.3: 64Kbps Transmission Power

Figure 6.4 reports the results obtained considering 3W HS-DSCH allocation power and 60% of cell radius. As shown, until 19 users the DCH channel is the more efficient channel in term of power consumption, while from 20 users onwards FACH and HS-DSCH should be used. It is important noting that, even if HS-DSCH and FACH have the same trend (3W), FACH is always preferable because it is able to serve more users than HS-DSCH (for example with 3W HS-DSCH can serve until 7 users while FACH can serve an unlimited number of users). The trend of the power using the chosen threshold is depicted in orange.

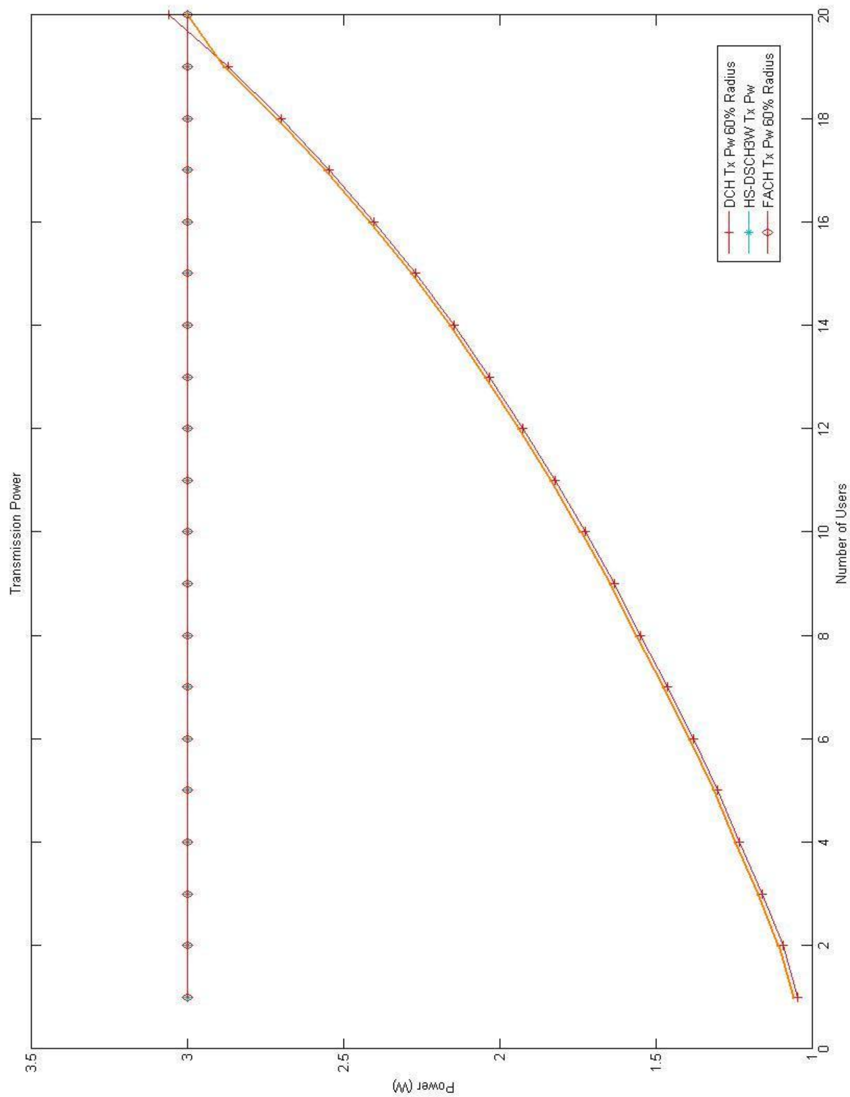

Figure 6.4:64Kbps Transmission Power for 60% Cell Radius

Figure 6.5 shows the results obtained considering 80% of cell radius. As shown in Table 5.2, for the above mentioned coverage percentage (80% of cell radius) the FA CH channel requires 4.8W. Thus, to find the cases in which HS-DSCH could be convenient, 3W or 4W HS-DSCH allocation powers need to be considered. Being that at 80% of cell radius, HS-DSCH with 4W can serve the same users number as with 3W (see Figure 6.2), the only reasonable value of transmission power for HS-DSCH is 3W. Using 3W of transmission power, HS-DSCH can serve until 7 users and so DCH is always preferable because it is able to serve the same number of users but requiring a lower transmission power (2.2971W). So as shown in Figure 6.5, until 17 users the DCH is the more efficient channel in term of power consumption, while from 18 users onwards FACH is preferable. The orange line in Figure 6.5 indicates the best power allocation mode for the considered percentage of cell radius (80%).

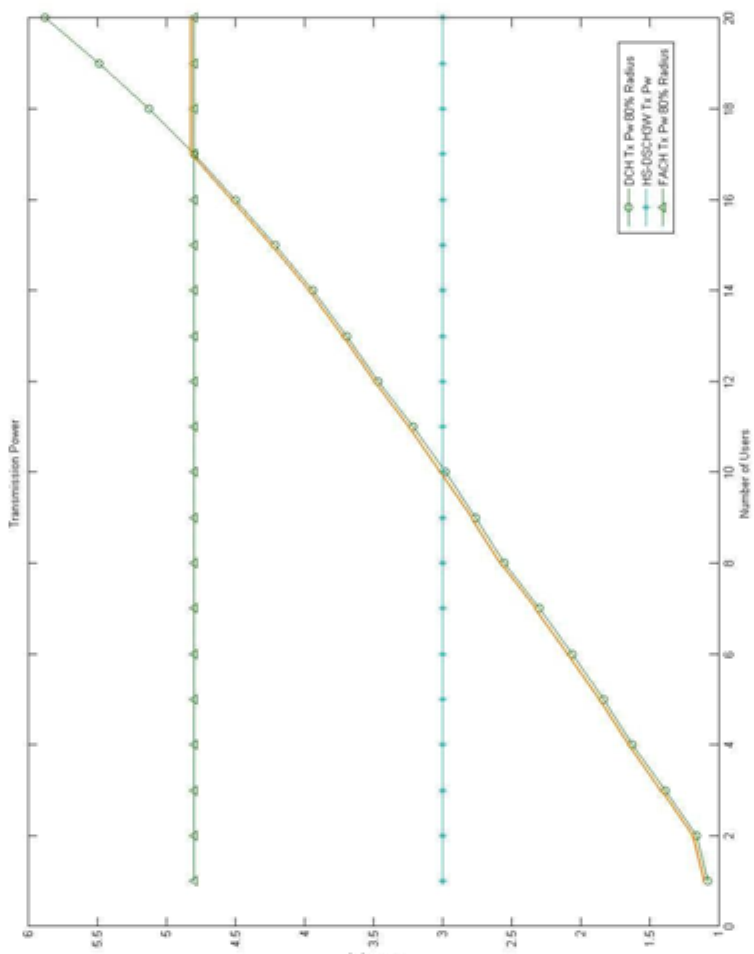

Figure 6.5:64Kbps Transmission Power for 80% Cell Radius

Figure 6.6 reports the results obtained considering 95% of cell radius. As shown in Table 5.2, for the above mentioned coverage percentage (95% of cell radius) the FACH channel requires 7.6W. Thus, to find the cases in which HS-DSCH could be convenient, 5W 6W and 7W HS-DSCH allocation powers need to be considered. At 80% of cell radius, HS-DSCH with 5W, 6W and 7W can serve respectively until 7, 15 and 22 users. As shown, the use of 5W HS-DSCH is not convenient because DCH can serve the same number of users as HS-DSCH but requiring a lower transmission power (4.416W). Using 6W, HS-DSCH can serve until 15 users and from 10 users is preferable to DCH which will require a greater transmission power (5.974). Evaluating the transmission power required to DCH and HS-DSCH to serve 15 users, it is possible to notice how much power can be preserved. In fact for this number of users HS-DSCH (6W) require 2.4907W less than DCH (8.4907W). Using 7W, HS-DSCH can serve until 22 users versus DCH which will require more than 12W. So as shown in Figure 6.6, until 10 users the DCH is the more efficient channel in term of power consumption, form 11 to 15 users HS-DSCH using 6W is preferable, while from 16 and until 22 users HS-DSCH using 7W is convenient. Over 22 users, FACH is the cheapest channel in term of power consumption. The orange line in Figure 6.6 indicates the best power allocation mode for the considered percentage of cell radius (95%).

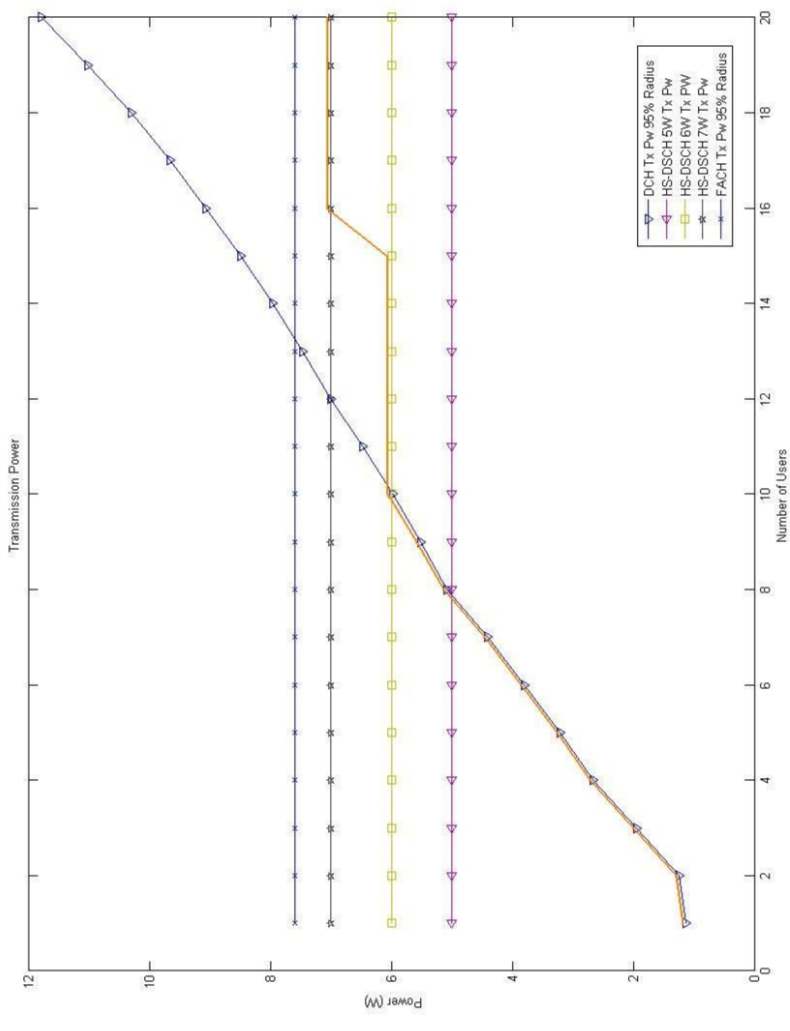

Figure 6.6: 64Kbps Transmission Power for 95% Cell Radius

The thresholds for all the percentages of cell radius are summarized in Table 6.3.

Table 6. 3: 64Kbps Switching Threshold

Number of Users Switching Threshold			
Radius	**DCH**	**HS-DSCH**	**FACH**
60%	< 20	never	=20
80%	=17	never	>17
95%	=10	(6W, SINR=22) 10=UE=15 ? (7W, SINR=23) 15<UE=22	>22

6.4 Switching Thresholds for 128Kbps MBMS Applications

When multiple DCHs are used, from a certain number of users the power needed will be higher than the power of FACH or HS-DSCH. This means that over that number of users it is cheaper, in terms of power consumption, to cover using a common or a shared channel than a dedicated channel. In Figure 6.7 the effect of increasing the number of users in the cell is presented for 128Kbps MBMS applications. The figure depicts how the switching points between DCHs and FACH or HS-DSCH change in function of the distance (or percentage of cell radius coverage) from the Node B. As expected, the switching threshold decreases increasing the distance.

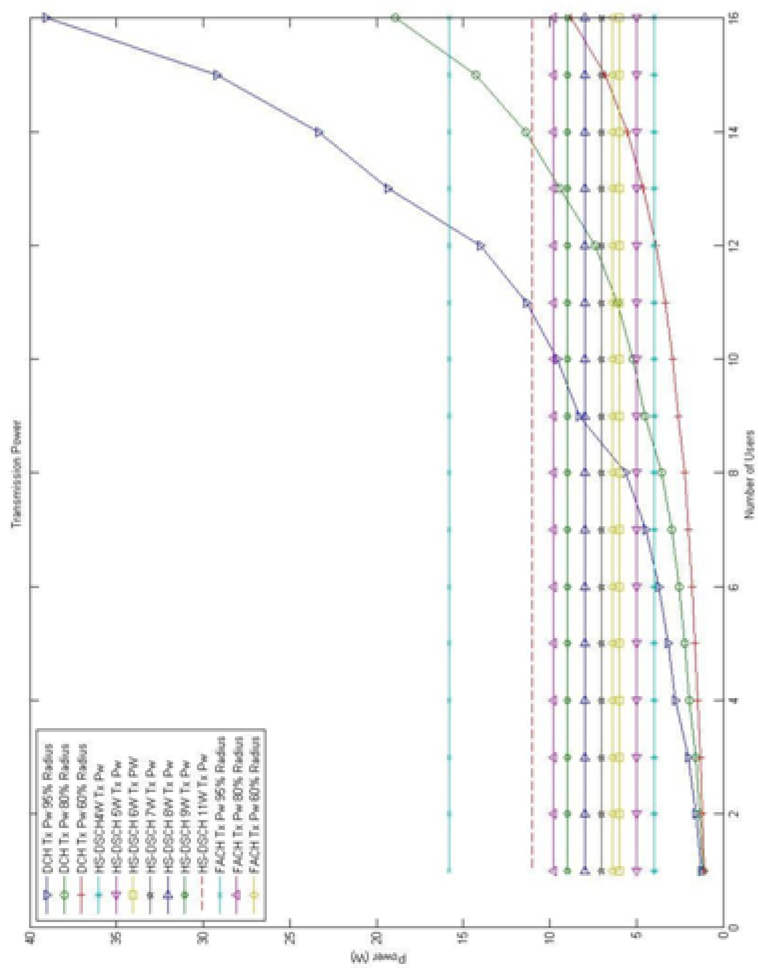

Figure 6.7:128Kbps Transmission Power

Figure 6.8 reports the results obtained considering 60% of cell radius. As shown in Table 5.2, for the above mentioned coverage percentage (60% of cell radius) the FACH channel requires 6.4W. Thus, to find the cases in which HS-DSCH could be convenient, 4W 5W and 6W HS-DSCH allocation powers need to be considered. At 60% of cell radius, HS-DSCH with 4W, 5W and 5W can serve respectively until 3, 7and 11 users. As shown, all these transmission power levels of HS-DSCH are not convenient because DCH can serve the same number of users as HS-DSCH but requiring a lower transmission power (1.3135W for 3 users, 1.98W for 7 users and 3.3164W for 11 users). As shown in Figure 6.8, until 14 users the DCH is the more efficient channel in term of power consumption, while from 15 users FACH is the cheapest channel in term of power consumption. The orange line in Figure 6.8 indicates the best power allocation mode for the considered percentage of cell radius (60%).

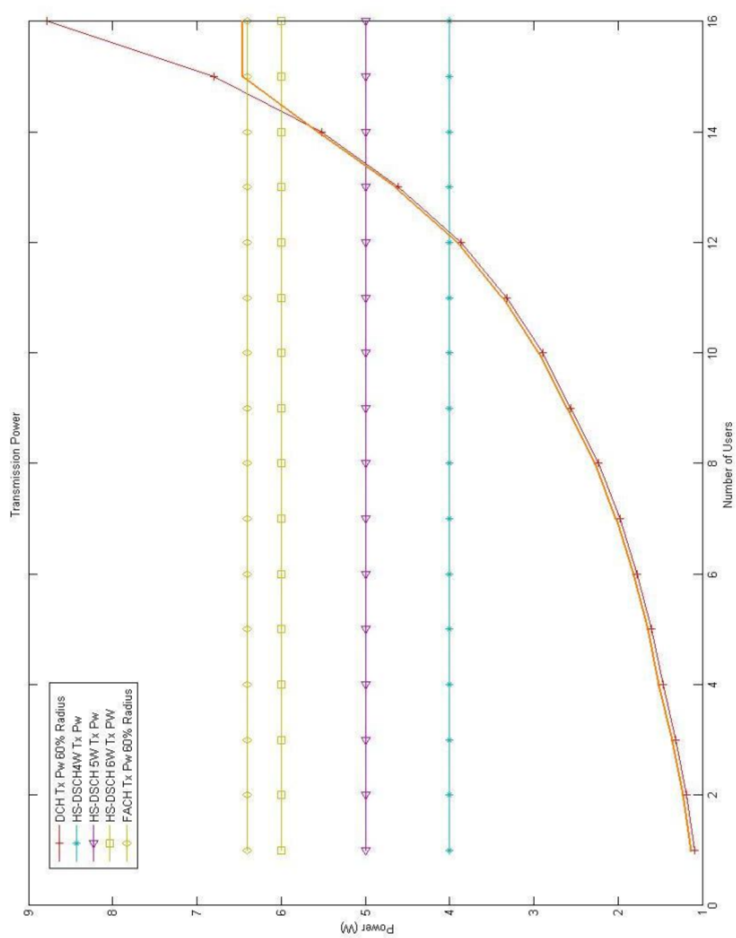

Figure 6.8 : 128Kbps Transmission Power for 60% Cell Radius

Figure 6.9 reports the results obtained considering 80% of cell radius. As shown in Table 5.2, for the above mentioned coverage percentage (80% of cell radius) the FACH channel requires 9.8W. Thus, to find the cases in which HS-DSCH could be convenient, 4W, 5W 7W and 8W HS-DSCH allocation powers need to be considered. At 80% of cell radius, HS-DSCH with 4W, 5W, 7W and 8W can serve respectively until 3, 7, 11 and 15 users. As shown, the use of 4W, 5W and 7W HS-DSCH is not convenient because DCH can serve the same number of users as HS-DSCH but requiring a lower transmission power (1.5953W for 3 users, 2.9553 for 7 users and 6.0885W for 11 users). Using 8W, HS-DSCH can serve until 15 users and from 13 users is preferable to DCH which will require a greater transmission power (9.4269W). Evaluating the transmission power required to DCH and HS-DSCH to serve 15 users, it is possible to notice how much power can be preserved. In fact for this number of users HS-DSCH (8W) require 6.2616W less than DCH (14.2616W). So as shown in Figure 6.9, until 12 users the DCH is the more efficient channel in term of power consumption, form 13 to 15 users HS-DSCH using 8W is preferable, while from 16 users FACH is the cheapest channel in term of power consumption. The orange line in Figure 6.9 indicates the best power allocation mode for the considered percentage of cell radius (80%).

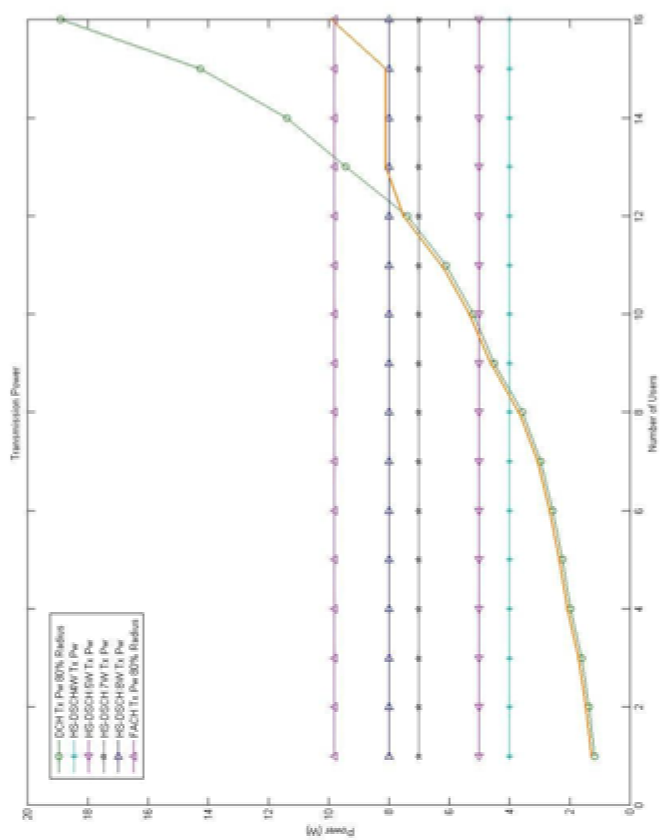

Figure 6.9 : 128Kbps Transmission Power for 80% Cell Radius

Figure 6.10 reports the results obtained considering 95% of cell radius. As shown in Table 5.2, for the above mentioned coverage percentage (95% of cell radius) the FACH channel requires 15.8W. Thus, to find the cases in which HS-DSCH could be convenient, 5W, 6W, 7W, 9W and 11W HS-DSCH allocation powers need to be considered. At 95% of cell radius, HS-DSCH with 5W, 6W, 7W, 9W and 11W can serve respectively until 3, 7, 11, 15 and 37 users. As shown, the use of 5W and 6W HS-DSCH is not convenient because DCH can serve the same number of users as HS-DSCH but requiring a lower transmission power (1.9947W for 3W users and 4.4461 for 7 users). Using 7W, HS-DSCH can serve until 11 users and from 9 users is preferable to DCH which will require a greater transmission power (8.309W). Evaluating the transmission power required to DCH and HS-DSCH to serve 11 users, it is possible to notice how much power can be preserved. In fact for this number of users HS-DSCH (7W) require 4.3095W less than DCH (11.3095W). Using 9W, HS-DSCH can serve until 15 users versus DCH which will require 29.2126W (over the total Node B transmission power). So as shown in Figure 6.10, until 8 users the DCH is the more efficient channel in term of power consumption, form 9 to 11 users HS-DSCH using 7W is preferable, while from 12 and until 15 users HS-DSCH using 9W is convenient. Form 16 and until 37 users HS-DSCH using 11W is preferable and over 37 users, FACH is the cheapest channel in term of power consumption. The orange line in Figure 6.10 indicates the best power allocation mode for the considered percentage of cell radius (95%).

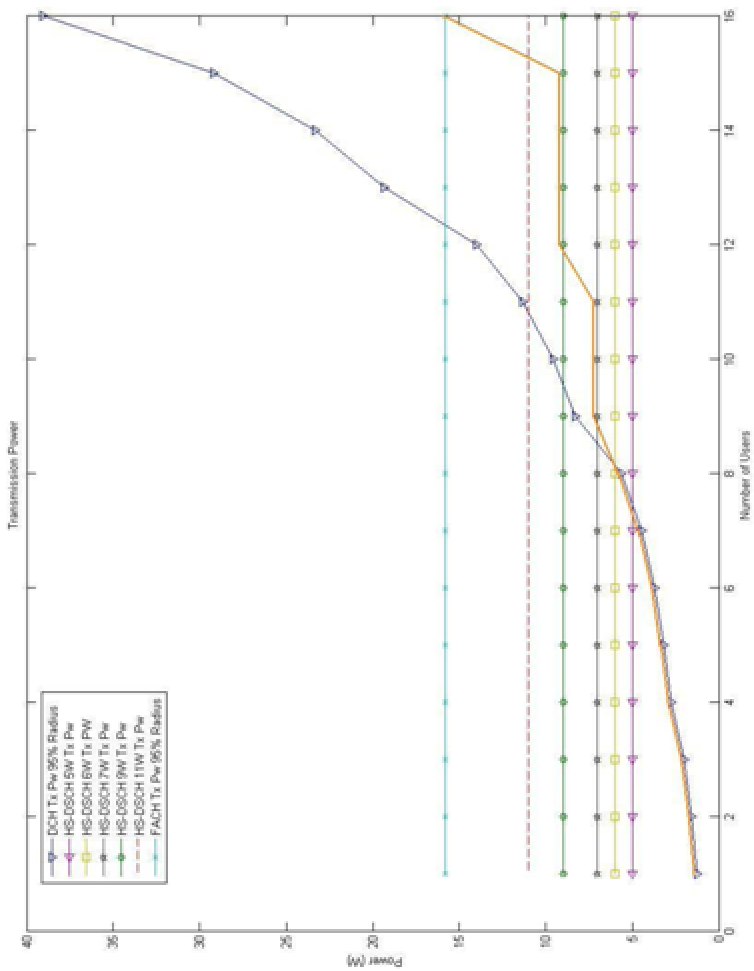

Figure 6.10: 128Kbps Transmission Power for 95% Cell Radius

The thresholds for all the percentages of cell radius for 128Kbit/s of data bit rate are summarized in Table 6.4.

Table 6. 4: 128Kbps Switching Threshold

Number of Users Switching Threshold			
Radius	**DCH**	**HS-DSCH**	**FACH**
60%	=14	never	>14
80%	=12	(8W, SINR=24) 12<UE=15	>15
95%	=8	(7W, SINR=23) 8<UE=11 ? (9W, SINR=24) 11<UE=15 ? (11W, SINR=25) 15<UE=37	>37

6.5 Switching Thresholds for 256Kbps MBMS Applications

In Figure 6. 11 the effect of increasing the number of users in the cell is presented for 256Kbps MBMS applications. The figure depicts how the switching points between DCHs and FACH or HS-DSCH change in function of the distance (or percentage of cell radius coverage) from the Node B. As expected, the switching threshold decreases increasing the distance.

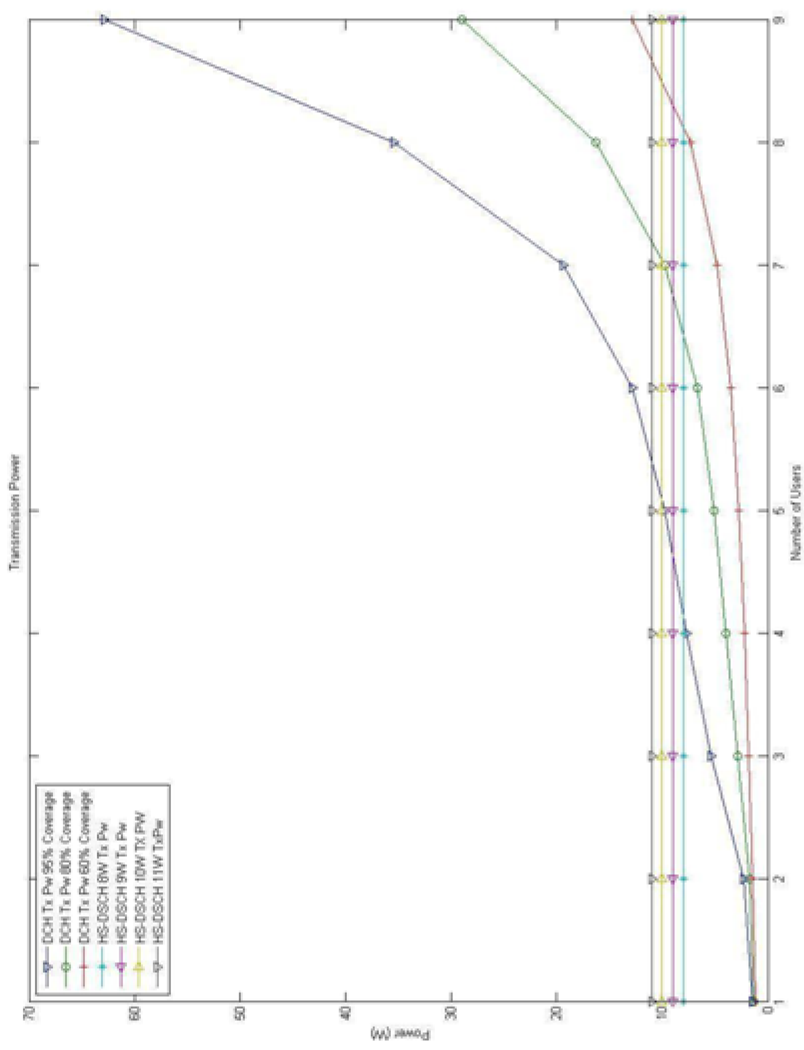

Figure 6. 11: 256Kbps Transmission Power

Figure 6.12 reports the results obtained considering 9W HS-DSCH allocation power and 60% of cell radius. As shown, until 8 users the DCH channel is the more efficient channel in term of power consumption, while from 9 users HS-DSCH should be used. Using 9W, HS-DSCH can serve until 18 users because the SINR for this percentage of radius is 24 dB (see Table 6.2 and Figure 6.2). The trend of the power using the chosen threshold is depicted in orange.

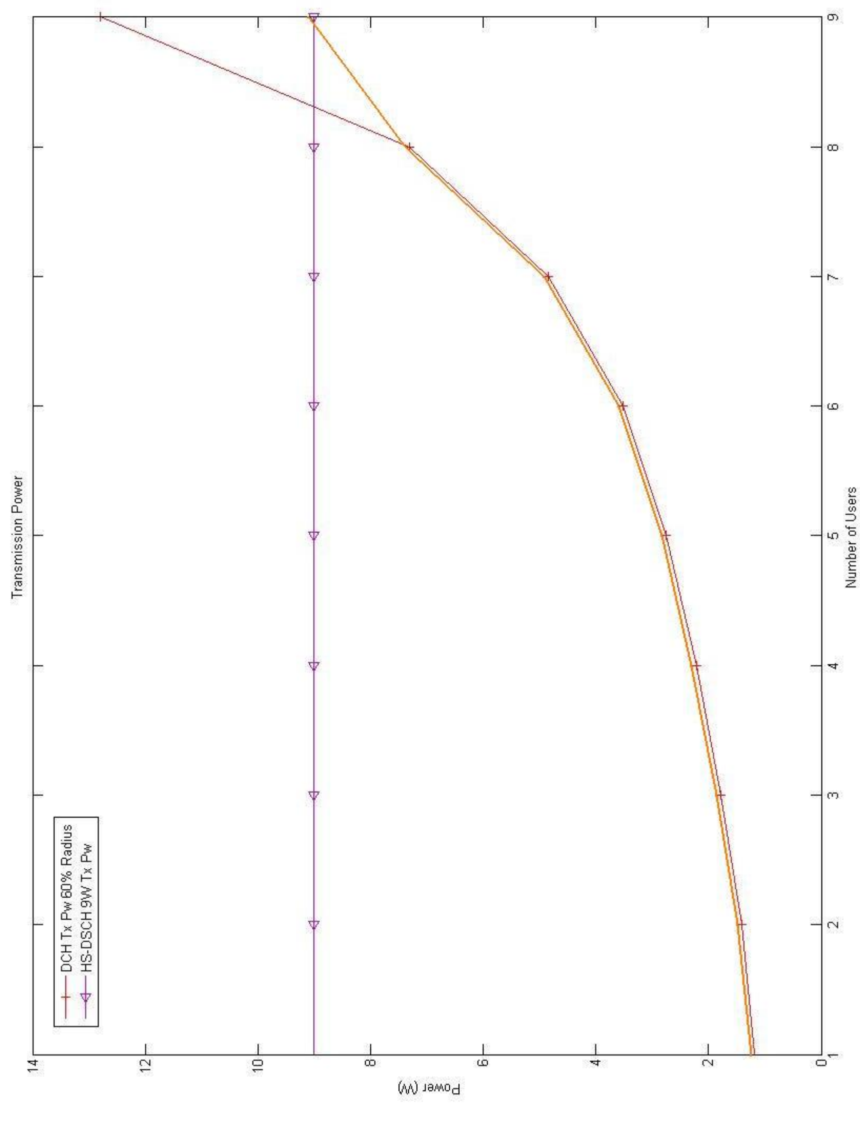

Figure 6.12: 256Kbps Transmission Power for 60% Cell Radius

Figure 6.13 reports the results obtained considering 80% of cell radius. The cases in which HS-DSCH could be convenient are for 8W and 10W. At 80% of cell radius, HS-DSCH with 8W and 10W can serve respectively until 7 and 18 users. To serve 7 users, HS-DSCH using 8W, is preferable to DCH which will require a greater transmission power (9. 3729W). Using 10W, HS-DSCH can serve until 18 users because the SINR for this percentage of radius is 25 dB (see Table 6.2 and Figure 6.2). Evaluating the transmission power required to DCH and HS-DSCH to serve 9 users, it is possible to notice how much power can be preserved. In fact for this number of users HS-DSCH (10W) requires 18.9481W less than DCH (28.9481W). So as shown in Figure 6. 13, until 6 users the DCH is the more efficient channel in term of power consumption, for 7 HS-DSCH using 8W is preferable, while from 8 users to 18 HS-DSCH using 10W is the cheapest channel in term of power consumption. For greater number of users HS-DSCH will always be the preferable channel. The orange line in Figure 6.13 indicates the best power allocation mode for the considered percentage of cell radius (80%).

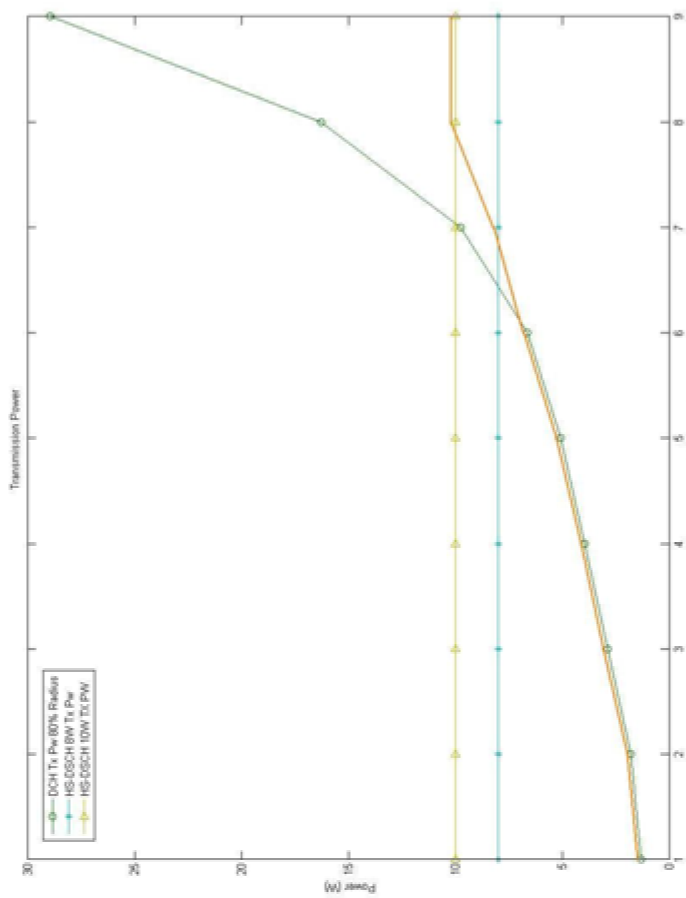

Figure 6. 13: 256Kbps Transmission Power for 80% Cell Radius

Figure 6.14 reports the results obtained considering 95% of cell radius. The cases in which HS-DSCH could be convenient are for 9W and 11W. At 80% of cell radius, HS-DSCH with 9W and 11W can serve respectively until 7 and 18 users. To serve 5 users, HS-DSCH using 9W, is preferable to DCH which will require a greater transmission power (9.7938W). Using 11W, HS-DSCH can serve until 18 users because the SINR for this percentage of radius is 25 dB (see Table 6.2 and Figure 6.2). Evaluating the transmission power required to DCH and HS-DSCH to serve 9 users, it is possible to notice how much power can be preserved. In fact for this number of users HS-DSCH (11W) requires 51.8274W less than DCH (62.8274W, over the total Node B transmission power). So as shown in Figure 6.14, until 4 users the DCH is the more efficient channel in term of power consumption, from 5 and until 7 users HS-DSCH using 9W is preferable, while from 8 users to 18 HS-DSCH using 11W is the cheapest channel in term of power consumption. For greater number of users HS-DSCH will always be the preferable channel. The orange line in Figure 6.14 indicates the best power allocation mode for the considered percentage of cell radius (95%).

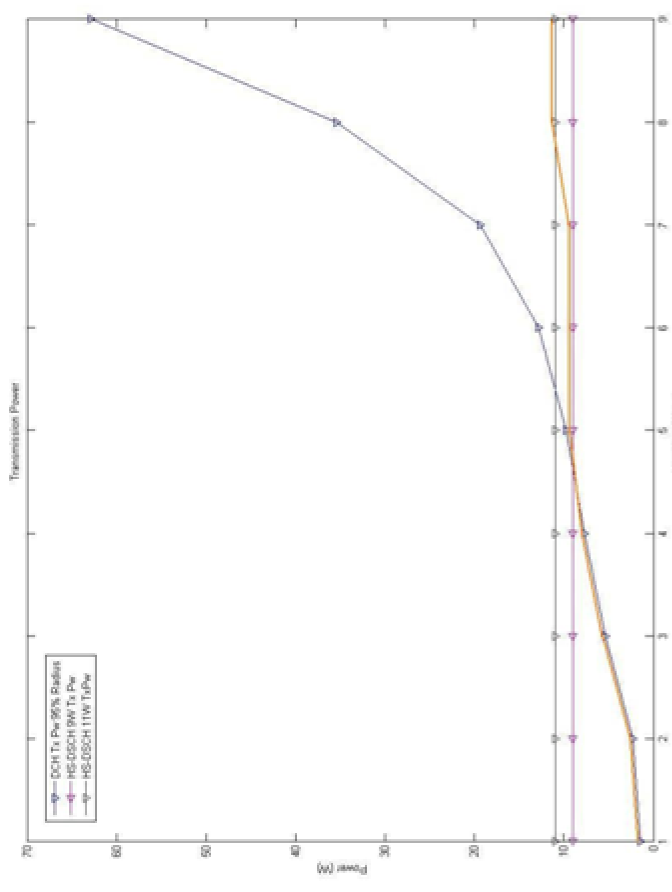

Figure 6.14: 256Kbps Transmission Power for 95% Cell Radius

The thresholds for all the percentages of cell radius for 256Kbit/s of data bit rate are summarized in Table 6.5.

Table 6.5: 256Kbps Switching Threshold

Number of Users Switching Threshold			
Radius	**DCH**	**HS-DSCH**	**FACH**
60%	=8	(9W, SINR=24) 8<UE=18	never
80%	=6	(8W, SINR=24) 6<UE=7 ? (10W, SINR=25) 7<UE=18	never
95%	=4	(9W, SINR=24) 4<UE=7 ? (11W, SINR=25) 7<UE=18	never

The thresholds mentioned in these paragraphs could be used for an efficient MBMS delivery. It has been shown how HS-DSCH can strongly decrease the power consumption in a MBMS session. Three data bit rate have been considered as well as three percentage of cell radius. For each case the most efficient transport channel in terms of power consumption has been chosen for each number of users. In fact, it has depicted the best power allocation mode for each data bit rate and each percentage of cell radius.

6.6 Thresholds Comparisons

This section shows how thresholds change in function of the application bit rate. Actually it is possible to see how power consumption changes in function of the bit rate for a fixed percentage of cell radius.

In Figure 6.15 results for 60% cell radius are shown. In this case when bit rate increases, the threshold to switch from a dedicated channel to a common channel decrease to 5 or 6 users.

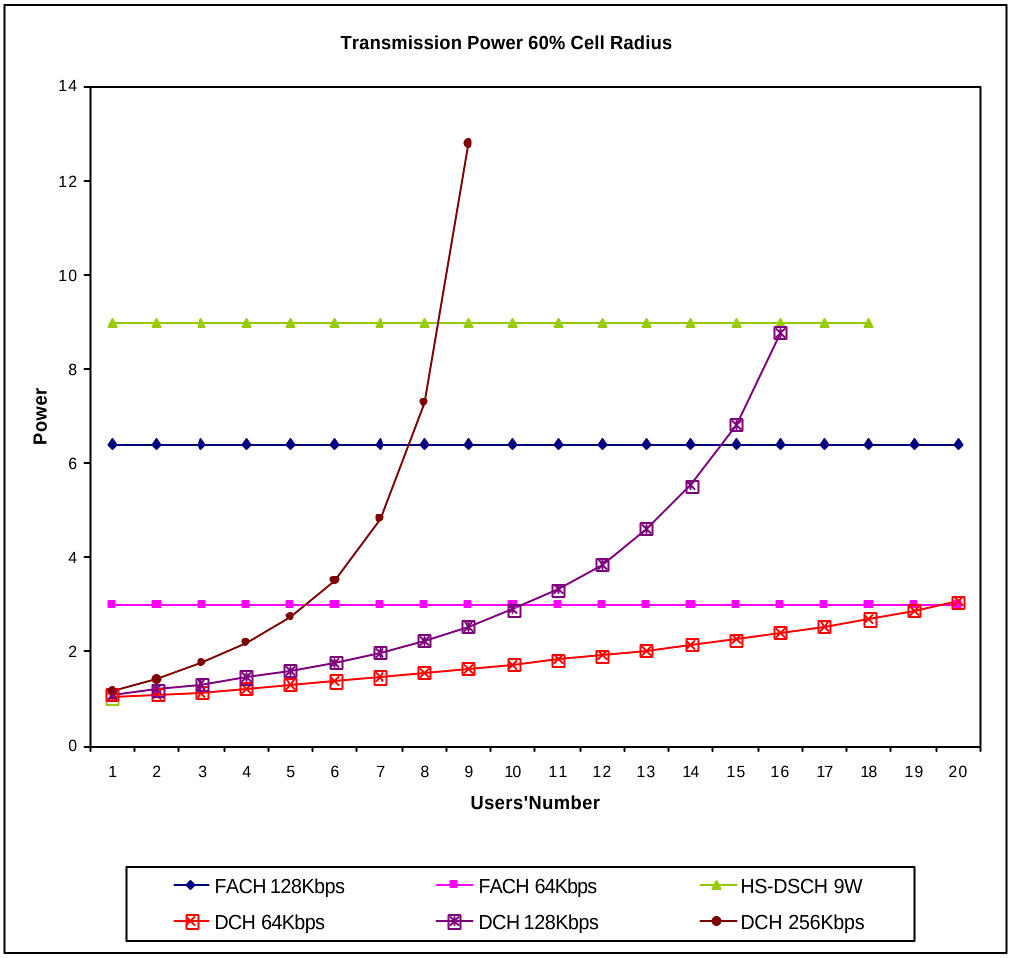

Figure 6. 155: Transmission Power for 60% Cell Radius

Table 6. 6: Switching Threshold for 60% Cell Radius

Number of Users Switching Threshold for 60% Cell Radius			
Bit Rate [Kbps]	**DCH**	**HS-DSCH**	**FACH**
64	< 20	never	=20
128	=14	never	>14
256	=8	(9W, SINR=24) 8<UE=18	never

In Figure 6.16 results for 80% cell radius are shown. Also in this case when bit rate increase, the threshold to switch from a dedicated channel to a common channel decrease to 5 or 6 users.

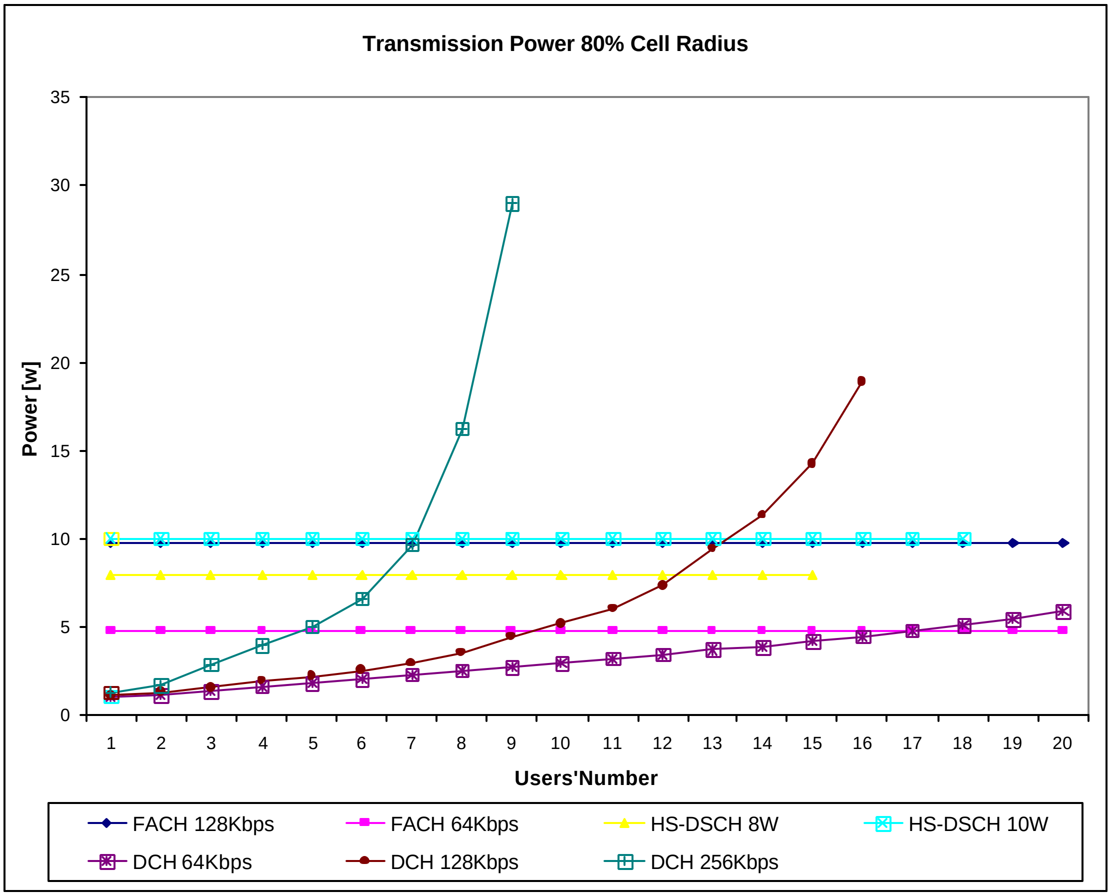

Figure 6. 166: Transmission Power for 80% Cell Radius

Table 6. 7: Switching Threshold for 80% Cell Radius

Number of Users Switching Threshold for 80% Cell Radius			
Bit Rate [Kbps]	**DCH**	**HS-DSCH**	**FACH**
64	=17	never	>17
128	=12	(8W, SINR=24) 12<UE=15	>15
256	=6	(8W, SINR=24) 6<UE=7 ? (10W, SINR=25) 7<UE=18	never

In Figure 6.17 results for 95% cell radius are shown. In this case when bit rate increase, the threshold to switch from a dedicated channe l to a common channel decrease to 2 users for 64Kbps to 128Kbps and 5 users from 128Kbps to 256Kbps.

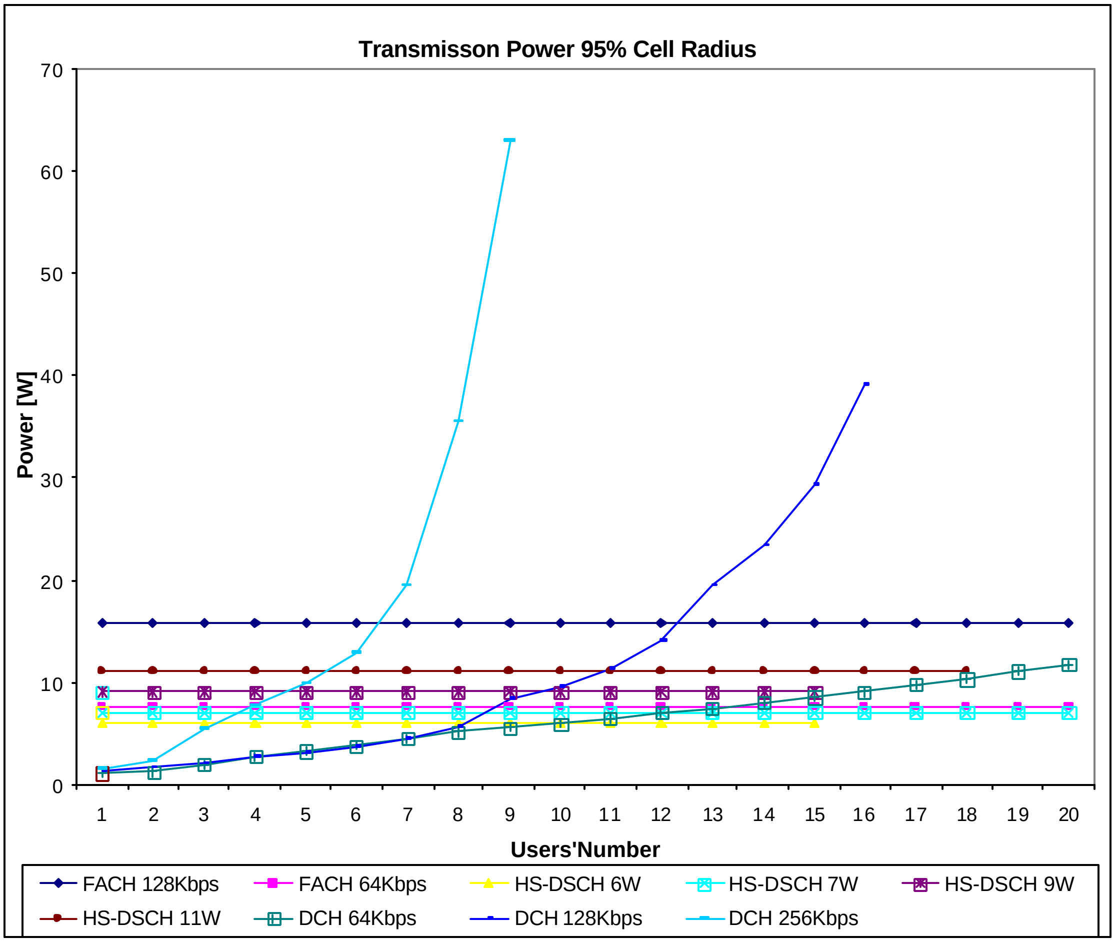

Figure 6. 177: Transmission Power for 95% Cell Radius

Table 6. 8: Switching Threshold for 95% Cell Radius

Number of Users Switching Threshold for 95 % Cell Radius			
Bit Rate [Kbps]	**DCH**	**HS-DSCH**	**FACH**
64	=10	(6W, SINR=22) 10=UE=15 ? (7W, SINR=23) 15<UE=22	>22
128	=8	(7W, SINR=23) 8<UE=11 ? (9W, SINR=24) 11<UE=15 ? (11W, SINR=25) 15<UE=37	>37
256	=4	(9W, SINR=24) 4<UE=7 ? (11W, SINR=25) 7<UE=18	never

6.7 Coverage by Multiple Channels

In this section coverage by using more than one channel is evaluated If users are not uniformly distributed, using one common channel which covers until the furthest user is not always the best choice. In fact evaluating the power needed to cover, for example, with a shared/broadcast channel in the area where users are more concentrated plus a dedicated channel for few distant users is a better power allocation solution. However if the number of users at 95% increases then the power needed to cover using multiple channel could be grater than to cover using a shared/common channel. For this study the thresholds for switch from a dedicated channel to a shared/common channel, described in the previous Sections (Section 6.3 to 6.6), have been used.

For each application bit rate four cases have been considered. First it has been considered the case when a shared or broadcast channel is used for 60% of cell radius and DCH for the users at 95% of cell radius. Second it has been considered the case when a shared or broadcast channel is used for 80% of cell radius and DCH for 95% of cell radius. Third it has been considered the case when a shared or broadcast channel is used for 60% cell radius and DCH is used for 80% cell radius. Finally it has been considered the case when DCH is used for both 95% and 80% of cell radius and a shared or common channel is used for 60% of cell radius. Of course, each time that DCH is used, for each given percentage of radius, it has been considered a number of users under the threshold to switch to a shared or to a common channel. In the last case, if the number of users at 80% cell radius will be grater than the threshold to switch to a shared/common channel the second case must be considered. All the results are in function of the number of the users. In the following paragraphs the thresholds for each bit rate are explained. When using multiple channels, for all possible channels combination, the sum of the common channel and dedicated channels transmission powers for the different percentages of cell radius has been calculated to obtain the total power required. Each obtained power value has been compared with the common/shared channel transmission power at the greater percentage of cell radius. From this comparison, the threshold to switch from multiple channels to the common/shared and the power saving percentage have been evaluated.

6.7.1 Coverage by Multiple Channels for 64Kbps

Figure 6.18, Figure 6.19 and Figure 6.20 depict the power needed to cover using multiple channels for 64Kbps.

In Figure 6.18 and Table 6.9 it is shown the power required for coverage using FACH for 60% plus DCH for 95% of cell radius, FACH for 80% plus DCH for 95% of cell radius and FACH for 95% of cell radius. For example, for three DCH channels at 95% of cell coverage, the transmission power required is 1.94W while FACH power at 60% of cell coverage is 3W. Thus, the total power required covering with multiple channels is 4.94W. This power value must be compared with FACH transmission power at 95% of cell coverage (7.6W). For this example the power saving obtained is 2.66W which correspond to 35.03%. The results show that from 8 DCHs at 95% plus FACH at 60% of cell radius and that from 5 DCHs at 95% plus FACH at 80% of cell radius onwards is preferable to cover using FACH at 95%. As shown in Table 6.9 it is possible a power saving until 41.13% in case of DCH at 95% plus FACH at 60% of cell radius and until 15.42% in case of DCH at 95% plus FACH at 80% of cell radius. From the above mentioned thresholds (red rows in the table) onwards it is always preferable to serve the users with common channel at the 95% of cell radius.

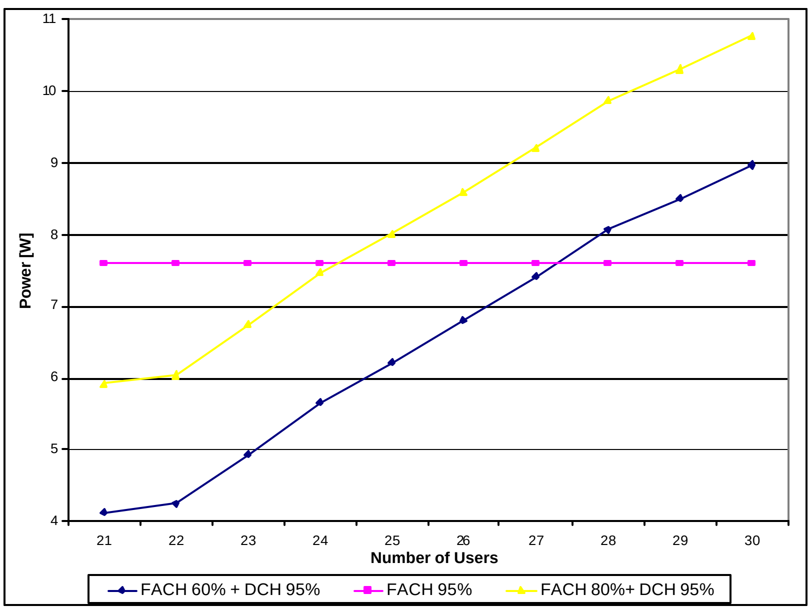

Figure 6.18: 95%+60% and 95%+80% Multiple Channel Coverage for 64Kbps

Table 6. 9: 95%+60% and 95%+80% Multiple channels coverage for 64Kbps

Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+60% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.12	20	FACH	3	4.12	21	HS-DSCH	7	41.1343
2	DCH	1.25	20	FACH	3	4.25	22	HS-DSCH	7	39.3186
3	DCH	1.94	20	FACH	3	4.94	23	FACH	7.6	35.0303
4	DCH	2.67	20	FACH	3	5.67	24	FACH	7.6	25.4316
5	DCH	3.22	20	FACH	3	6.22	25	FACH	7.6	18.2132
6	DCH	3.8	20	FACH	3	6.8	26	FACH	7.6	10.5579
7	DCH	4.42	20	FACH	3	7.42	27	FACH	7.6	2.42105
8	DCH	5.07	20	FACH	3	8.07	28	FACH	7.6	-6.2395
9	DCH	5.51	20	FACH	3	8.51	29	FACH	7.6	-11.962
10	DCH	5.97	20	FACH	3	8.97	30	FACH	7.6	-18.079
Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 80%	Channel for 80%	Power 80% [W]	Total Power 95%+80% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.12	20	FACH	4.8	5.92	21	HS-DSCH	7	15.42
2	DCH	1.25	20	FACH	4.8	6.05	22	HS-DSCH	7	13.6043
3	DCH	1.94	20	FACH	4.8	6.74	23	FACH	7.6	11.3461
4	DCH	2.67	20	FACH	4.8	7.47	24	FACH	7.6	1.74737
5	DCH	3.22	20	FACH	4.8	8.02	25	FACH	7.6	-5.4711
6	DCH	3.8	20	FACH	4.8	8.6	26	FACH	7.6	-13.126
7	DCH	4.42	20	FACH	4.8	9.22	27	FACH	7.6	-21.263
8	DCH	5.07	20	FACH	4.8	9.87	28	FACH	7.6	-29.924
9	DCH	5.51	20	FACH	4.8	10.3	29	FACH	7.6	-35.646
10	DCH	5.97	20	FACH	4.8	10.8	30	FACH	7.6	-41.763

In Figure 6.19 and Table 6.10 it is shown the power required for coverage using FACH for 60% plus DCH for 80% of cell radius and FACH for 80% of cell radius. For example, for three DCH channels at 80% of cell coverage, the transmission power required is 1.38W while FACH power at 60% of cell coverage is 3W. Thus, the total power required covering with multiple channels is 4.38W. This power value must be compared with FACH transmission power at 80% of cell coverage (4.8W). For this example the power saving obtained is 0.42W which correspond to 8.68%. The results show that from 5 DCHs at 80% plus FACH at 60% of cell onwards is preferable to cover using FACH at 80%. As shown in Table 610, in this case it is possible a power saving until 15.07%. From the above mentioned threshold (red row in the table) onwards it is always preferable to serve the users with common channel at the 80% of cell radius.

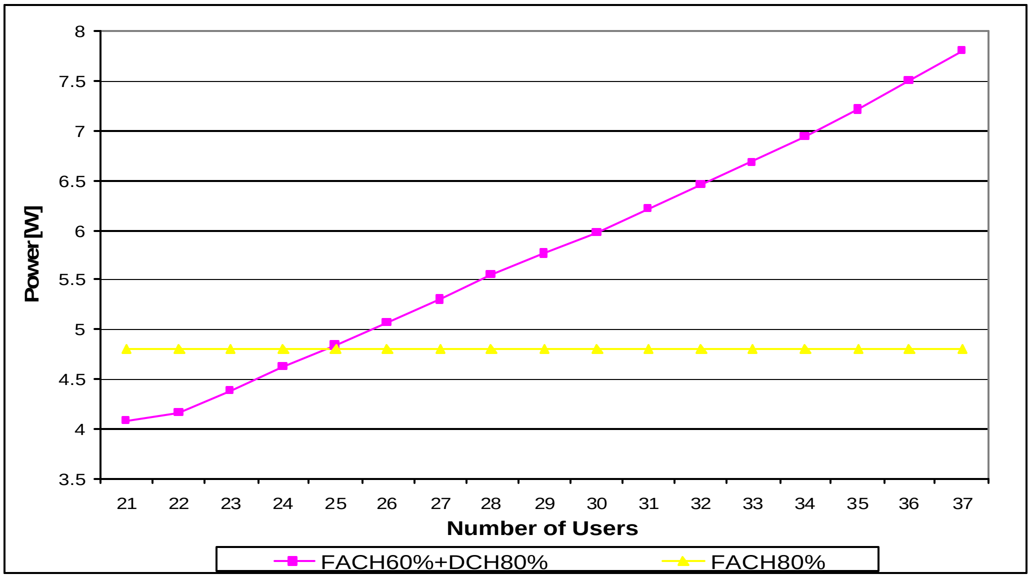

Figure 6.19: 80%+60% Multiple channels coverage for 64Kbps

Table 6. 10 : 80%+60% Multiple channels coverage for 64Kbps

Number of UEs at 80%	Channel for 80%	Power 80% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+60% [W]	Total UE	Channel for all UE at 80%	Total power for all UE at 80%	Power Saving %
1	DCH	1.08	20	FACH	3	4.08	21	FACH	4.8	15.0688
2	DCH	1.16	20	FACH	3	4.16	22	FACH	4.8	13.3833
3	DCH	1.38	20	FACH	3	4.38	23	FACH	4.8	8.6875
4	DCH	1.62	20	FACH	3	4.62	24	FACH	4.8	3.72292
5	DCH	1.83	20	FACH	3	4.83	25	FACH	4.8	-0.6937
6	DCH	2.06	20	FACH	3	5.06	26	FACH	4.8	-5.3792
7	DCH	2.3	20	FACH	3	5.3	27	FACH	4.8	-10.356
8	DCH	2.55	20	FACH	3	5.55	28	FACH	4.8	-15.656
9	DCH	2.76	20	FACH	3	5.76	29	FACH	4.8	-19.923
10	DCH	2.98	20	FACH	3	5.98	30	FACH	4.8	-24.485
11	DCH	3.21	20	FACH	3	6.21	31	FACH	4.8	-29.375
12	DCH	3.46	20	FACH	3	6.46	32	FACH	4.8	-34.627
13	DCH	3.69	20	FACH	3	6.69	33	FACH	4.8	-39.4
14	DCH	3.94	20	FACH	3	6.94	34	FACH	4.8	-44.556
15	DCH	4.21	20	FACH	3	7.21	35	FACH	4.8	-50.144
16	DCH	4.5	20	FACH	3	7.5	36	FACH	4.8	-56.219
17	DCH	4.8	20	FACH	3	7.8	37	FACH	4.8	-62.415

In Figure 6.20 and Table 6.11 it is shown the power required for coverage using FACH for 60% plus DCH for 80% and DCH for 95% of cell radius and FACH for 95% of cell radius. For example, for one DCH channel at 95% of cell coverage, the transmission power required is 1.12W and for three DCH channels at 80% of cell coverage, the transmission power required is 1.38W while FACH power at 60% of cell coverage is 3W. Thus, the total power required covering with multiple channels is 5.5036W. This power value must be compared with FACH transmission power at 95% of cell coverage (7.6W). For this example the power saving obtained is 2.0964W which correspond to 27.58%. The results show that from 1 DCH at 95% plus 13 DCHs at 80% plus FACH at 60% of cell radius, from 2 DCH at 95% plus 12 DCHs at 80% plus FACH at 60% of cell radius, from 3 DCH at 95% plus 9 DCHs at 80% plus FACH at 60% of cell radius, from 4 DCH at 95% plus 6 DCHs at 80% plus FACH at 60% of cell radius, from 5 DCH at 95% plus 4 DCHs at 80% plus FACH at 60% of cell radius and from 6 DCH at 95% plus 1 DCHs at 80% plus FACH at 60% of cell radius onwards is preferable to cover using FACH at 95%. As shown in Table 611 it is possible a power saving until 31.61%. From the above mentioned thresholds (red rows in the table) onwards it is always preferable to serve the users with common channel at the 95% of cell radius.

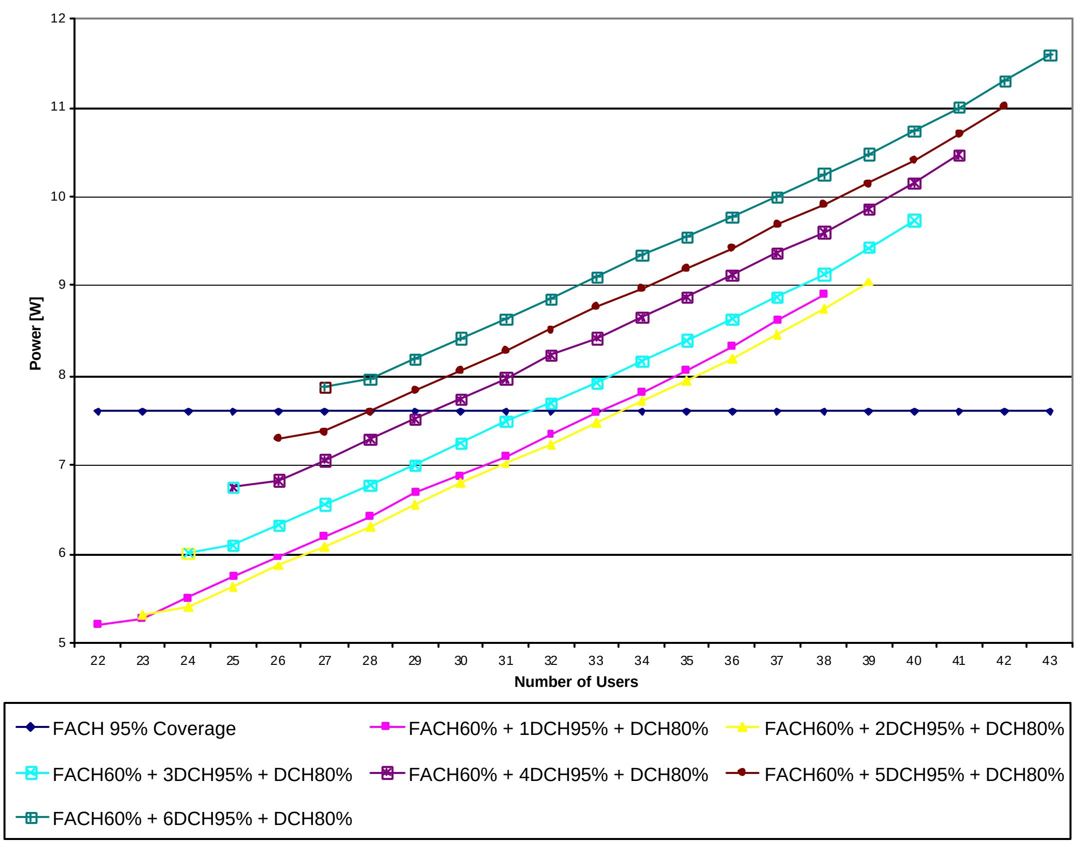

Figure 6.20: 95%+80%+60% Multiple channels coverage for 64Kbps

Table 6. 11 : 95%+80%+60% Multiple channels coverage for 64Kbps

Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 80%	Channel for 80%	Power 80% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+80% +60% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.12	1	DCH	1.08	20	FACH	3	5.1973	22	FACH	7.6	31.614474
1	DCH	1.12	2	DCH	1.16	20	FACH	3	5.2782	23	FACH	7.6	30.55
1	DCH	1.12	3	DCH	1.38	20	FACH	3	5.5036	24	FACH	7.6	27.584211
1	DCH	1.12	4	DCH	1.62	20	FACH	3	5.7419	25	FACH	7.6	24.448684
1	DCH	1.12	5	DCH	1.83	20	FACH	3	5.9539	26	FACH	7.6	21.659211
1	DCH	1.12	6	DCH	2.06	20	FACH	3	6.1788	27	FACH	7.6	18.7
1	DCH	1.12	7	DCH	2.3	20	FACH	3	6.4177	28	FACH	7.6	15.556579
1	DCH	1.12	8	DCH	2.55	20	FACH	3	6.6721	29	FACH	7.6	12.209211
1	DCH	1.12	9	DCH	2.76	20	FACH	3	6.8769	30	FACH	7.6	9.5144737
1	DCH	1.12	10	DCH	2.98	20	FACH	3	7.0959	31	FACH	7.6	6.6328947
1	DCH	1.12	11	DCH	3.21	20	FACH	3	7.3306	32	FACH	7.6	3.5447368
1	DCH	1.12	12	DCH	3.46	20	FACH	3	7.5827	33	FACH	7.6	0.2276316
1	DCH	1.12	13	DCH	3.69	20	FACH	3	7.8118	34	FACH	7.6	-2.7868421
1	DCH	1.12	14	DCH	3.94	20	FACH	3	8.0593	35	FACH	7.6	-6.0434211
1	DCH	1.12	15	DCH	4.21	20	FACH	3	8.3275	36	FACH	7.6	-9.5723684
1	DCH	1.12	16	DCH	4.5	20	FACH	3	8.6191	37	FACH	7.6	-13.409211
1	DCH	1.12	17	DCH	4.8	20	FACH	3	8.9165	38	FACH	7.6	-17.322368
2	DCH	1.25	1	DCH	1.08	20	FACH	3	5.3244	23	FACH	7.6	29.942105
2	DCH	1.25	2	DCH	1.16	20	FACH	3	5.4053	24	FACH	7.6	28.877632
2	DCH	1.25	3	DCH	1.38	20	FACH	3	5.6307	25	FACH	7.6	25.911842
2	DCH	1.25	4	DCH	1.62	20	FACH	3	5.869	26	FACH	7.6	22.776316
2	DCH	1.25	5	DCH	1.83	20	FACH	3	6.081	27	FACH	7.6	19.986842
2	DCH	1.25	6	DCH	2.06	20	FACH	3	6.3059	28	FACH	7.6	17.027632
2	DCH	1.25	7	DCH	2.3	20	FACH	3	6.5448	29	FACH	7.6	13.884211
2	DCH	1.25	8	DCH	2.55	20	FACH	3	6.7992	30	FACH	7.6	10.536842
2	DCH	1.25	9	DCH	2.76	20	FACH	3	7.004	31	FACH	7.6	7.8421053
2	DCH	1.25	10	DCH	2.98	20	FACH	3	7.223	32	FACH	7.6	4.9605263
2	DCH	1.25	11	DCH	3.21	20	FACH	3	7.4577	33	FACH	7.6	1.8723684
2	DCH	1.25	12	DCH	3.46	20	FACH	3	7.7098	34	FACH	7.6	-1.4447368
2	DCH	1.25	13	DCH	3.69	20	FACH	3	7.9389	35	FACH	7.6	-4.4592105
2	DCH	1.25	14	DCH	3.94	20	FACH	3	8.1864	36	FACH	7.6	-7.7157895
2	DCH	1.25	15	DCH	4.21	20	FACH	3	8.4546	37	FACH	7.6	-11.244737
2	DCH	1.25	16	DCH	4.5	20	FACH	3	8.7462	38	FACH	7.6	-15.081579
2	DCH	1.25	17	DCH	4.8	20	FACH	3	9.0436	39	FACH	7.6	-18.994737
3	DCH	1.94	1	DCH	1.08	20	FACH	3	6.0144	24	FACH	7.6	20.863158
3	DCH	1.94	2	DCH	1.16	20	FACH	3	6.0953	25	FACH	7.6	19.798684
3	DCH	1.94	3	DCH	1.38	20	FACH	3	6.3207	26	FACH	7.6	16.832895
3	DCH	1.94	4	DCH	1.62	20	FACH	3	6.559	27	FACH	7.6	13.697368
3	DCH	1.94	5	DCH	1.83	20	FACH	3	6.771	28	FACH	7.6	10.907895
3	DCH	1.94	6	DCH	2.06	20	FACH	3	6.9959	29	FACH	7.6	7.9486842
3	DCH	1.94	7	DCH	2.3	20	FACH	3	7.2348	30	FACH	7.6	4.8052632
3	DCH	1.94	8	DCH	2.55	20	FACH	3	7.4892	31	FACH	7.6	1.4578947
3	DCH	1.94	9	DCH	2.76	20	FACH	3	7.694	32	FACH	7.6	-1.2368421
3	DCH	1.94	10	DCH	2.98	20	FACH	3	7.913	33	FACH	7.6	-4.1184211
3	DCH	1.94	11	DCH	3.21	20	FACH	3	8.1477	34	FACH	7.6	-7.2065789

3	DCH	1.94	12	DCH	3.46	20	FACH	3	8.3998	35	FACH	7.6	-10.523684
3	DCH	1.94	13	DCH	3.69	20	FACH	3	8.6289	36	FACH	7.6	-13.538158
3	DCH	1.94	14	DCH	3.94	20	FACH	3	8.8764	37	FACH	7.6	-16.794737
3	DCH	1.94	15	DCH	4.21	20	FACH	3	9.1446	38	FACH	7.6	-20.323684
3	DCH	1.94	16	DCH	4.5	20	FACH	3	9.4362	39	FACH	7.6	-24.160526
3	DCH	1.94	17	DCH	4.8	20	FACH	3	9.7336	40	FACH	7.6	-28.073684
4	DCH	2.67	1	DCH	1.08	20	FACH	3	6.7439	25	FACH	7.6	11.264474
4	DCH	2.67	2	DCH	1.16	20	FACH	3	6.8248	26	FACH	7.6	10.2
4	DCH	2.67	3	DCH	1.38	20	FACH	3	7.0502	27	FACH	7.6	7.2342105
4	DCH	2.67	4	DCH	1.62	20	FACH	3	7.2885	28	FACH	7.6	4.0986842
4	DCH	2.67	5	DCH	1.83	20	FACH	3	7.5005	29	FACH	7.6	1.3092105
4	DCH	2.67	6	DCH	2.06	20	FACH	3	7.7254	30	FACH	7.6	-1.65
4	DCH	2.67	7	DCH	2.3	20	FACH	3	7.9643	31	FACH	7.6	-4.7934211
4	DCH	2.67	8	DCH	2.55	20	FACH	3	8.2187	32	FACH	7.6	-8.1407895
4	DCH	2.67	9	DCH	2.76	20	FACH	3	8.4235	33	FACH	7.6	-10.835526
4	DCH	2.67	10	DCH	2.98	20	FACH	3	8.6425	34	FACH	7.6	-13.717105
4	DCH	2.67	11	DCH	3.21	20	FACH	3	8.8772	35	FACH	7.6	-16.805263
4	DCH	2.67	12	DCH	3.46	20	FACH	3	9.1293	36	FACH	7.6	-20.122368
4	DCH	2.67	13	DCH	3.69	20	FACH	3	9.3584	37	FACH	7.6	-23.136842
4	DCH	2.67	14	DCH	3.94	20	FACH	3	9.6059	38	FACH	7.6	-26.393421
4	DCH	2.67	15	DCH	4.21	20	FACH	3	9.8741	39	FACH	7.6	-29.922368
4	DCH	2.67	16	DCH	4.5	20	FACH	3	10.166	40	FACH	7.6	-33.759211
4	DCH	2.67	17	DCH	4.8	20	FACH	3	10.463	41	FACH	7.6	-37.672368
5	DCH	3.22	1	DCH	1.08	20	FACH	3	7.2925	26	FACH	7.6	4.0460526
5	DCH	3.22	2	DCH	1.16	20	FACH	3	7.3734	27	FACH	7.6	2.9815789
5	DCH	3.22	3	DCH	1.38	20	FACH	3	7.5988	28	FACH	7.6	0.0157895
5	DCH	3.22	4	DCH	1.62	20	FACH	3	7.8371	29	FACH	7.6	-3.1197368
5	DCH	3.22	5	DCH	1.83	20	FACH	3	8.0491	30	FACH	7.6	-5.9092105
5	DCH	3.22	6	DCH	2.06	20	FACH	3	8.274	31	FACH	7.6	-8.8684211
5	DCH	3.22	7	DCH	2.3	20	FACH	3	8.5129	32	FACH	7.6	-12.011842
5	DCH	3.22	8	DCH	2.55	20	FACH	3	8.7673	33	FACH	7.6	-15.359211
5	DCH	3.22	9	DCH	2.76	20	FACH	3	8.9721	34	FACH	7.6	-18.053947
5	DCH	3.22	10	DCH	2.98	20	FACH	3	9.1911	35	FACH	7.6	-20.935526
5	DCH	3.22	11	DCH	3.21	20	FACH	3	9.4258	36	FACH	7.6	-24.023684
5	DCH	3.22	12	DCH	3.46	20	FACH	3	9.6779	37	FACH	7.6	-27.340789
5	DCH	3.22	13	DCH	3.69	20	FACH	3	9.907	38	FACH	7.6	-30.355263
5	DCH	3.22	14	DCH	3.94	20	FACH	3	10.155	39	FACH	7.6	-33.611842
5	DCH	3.22	15	DCH	4.21	20	FACH	3	10.423	40	FACH	7.6	-37.140789
5	DCH	3.22	16	DCH	4.5	20	FACH	3	10.714	41	FACH	7.6	-40.977632
5	DCH	3.22	17	DCH	4.8	20	FACH	3	11.012	42	FACH	7.6	-44.890789
6	DCH	3.8	1	DCH	1.08	20	FACH	3	7.8743	27	FACH	7.6	-3.6092105
6	DCH	3.8	2	DCH	1.16	20	FACH	3	7.9552	28	FACH	7.6	-4.6736842
6	DCH	3.8	3	DCH	1.38	20	FACH	3	8.1806	29	FACH	7.6	-7.6394737
6	DCH	3.8	4	DCH	1.62	20	FACH	3	8.4189	30	FACH	7.6	-10.775
6	DCH	3.8	5	DCH	1.83	20	FACH	3	8.6309	31	FACH	7.6	-13.564474
6	DCH	3.8	6	DCH	2.06	20	FACH	3	8.8558	32	FACH	7.6	-16.523684
6	DCH	3.8	7	DCH	2.3	20	FACH	3	9.0947	33	FACH	7.6	-19.667105
6	DCH	3.8	8	DCH	2.55	20	FACH	3	9.3491	34	FACH	7.6	-23.014474
6	DCH	3.8	9	DCH	2.76	20	FACH	3	9.5539	35	FACH	7.6	-25.709211

6	DCH	3.8	10	DCH	2.98	20	FACH	3	9.7729	36	FACH	7.6	-28.590789
6	DCH	3.8	11	DCH	3.21	20	FACH	3	10.008	37	FACH	7.6	-31.678947
6	DCH	3.8	12	DCH	3.46	20	FACH	3	10.26	38	FACH	7.6	-34.996053
6	DCH	3.8	13	DCH	3.69	20	FACH	3	10.489	39	FACH	7.6	-38.010526
6	DCH	3.8	14	DCH	3.94	20	FACH	3	10.736	40	FACH	7.6	-41.267105
6	DCH	3.8	15	DCH	4.21	20	FACH	3	11.005	41	FACH	7.6	-44.796053
6	DCH	3.8	16	DCH	4.5	20	FACH	3	11.296	42	FACH	7.6	-48.632895
6	DCH	3.8	17	DCH	4.8	20	FACH	3	11.594	43	FACH	7.6	-52.546053

6.7.2 Coverage by Multiple Channels for 128Kbps

Figure 6.21, Figure 6.22 and Figure 6.23 depict the power needed to cover using multiple channels for 128Kbps.

In Figure 6.21 and Table 6.12 it is shown the power required for coverage using FACH for 60% plus DCH for 95% of cell radius, FACH for 80% plus DCH for 95% of cell radius and FACH for 95% of cell radius. For example, for three DCH channels at 95% of cell coverage, the transmission power required is 1.995W while FACH power at 60% of cell coverage is 6.4W. Thus, the total power required covering with multiple channels is 8.4W. This power value must be compared with HS-DSCH transmission power at 95% of cell coverage (11W). For this example the power saving obtained is 2.6W which correspond to 23.68%. The results show that from 8 DCHs at 95% plus FACH at 60% of cell radius and that from 5 DCHs at 95% plus FACH at 80% (the same results of 64Kbps, but here HS-DSCH is used) of cell radius onwards is preferable to cover using FACH at 95%. As shown in Table 6.12 it is possible a power saving until 30.53% in case of DCH at 95% plus FACH at 60% of cell radius and until 15.98% in case of DCH at 95% plus FACH at 80% of cell radius. From the above mentioned thresholds (red rows in the table) onwards it is always preferable to serve the users with shared channel at the 95% of cell radius.

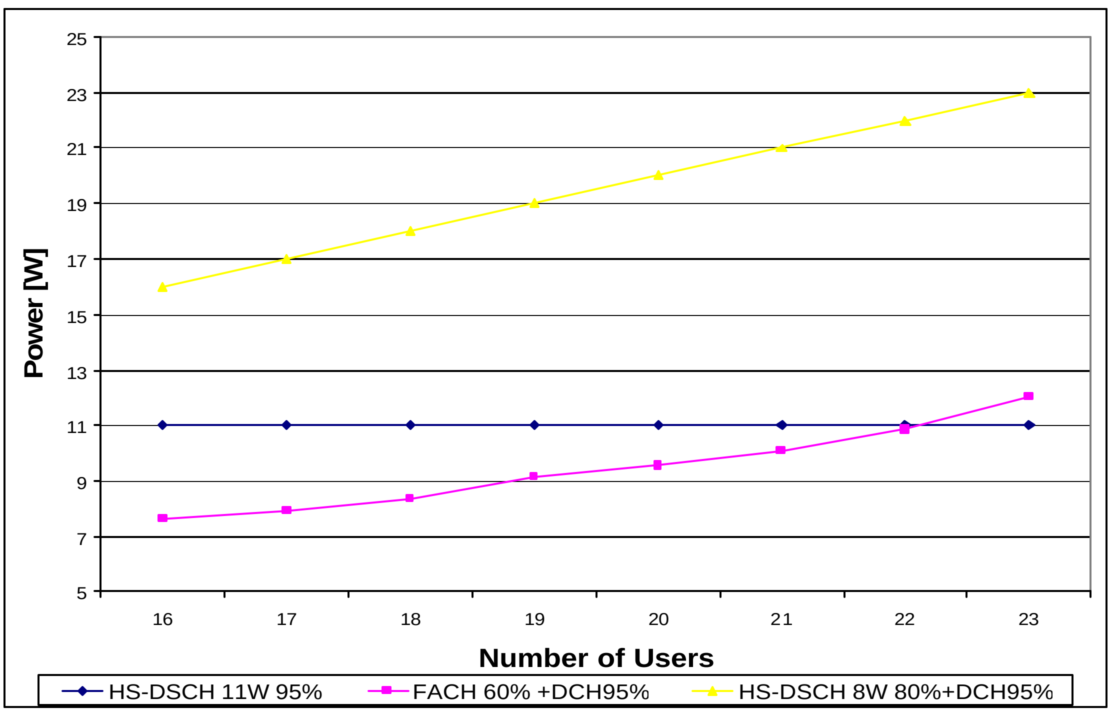

Figure 6.21 : 95%+80% and 95%+60% Multiple channels coverage for 128Kbps

Table 6. 12: 95%+80% and 95%+60% Multiple channels coverage for 128Kbps

Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+60% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.241	15	FACH	6.4	7.6	16	HS-DSCH	11	30.53455
2	DCH	1.552	15	FACH	6.4	8	17	HS-DSCH	11	27.71091
3	DCH	1.995	15	FACH	6.4	8.4	18	HS-DSCH	11	23.68455
4	DCH	2.742	15	FACH	6.4	9.1	19	HS-DSCH	11	16.89091
5	DCH	3.164	15	FACH	6.4	9.6	20	HS-DSCH	11	13.05545
6	DCH	3.701	15	FACH	6.4	10	21	HS-DSCH	11	8.171818
7	DCH	4.446	15	FACH	6.4	11	22	HS-DSCH	11	1.399091
8	DCH	5.648	15	FACH	6.4	12	23	HS-DSCH	11	-9.52455
Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 80%	Channel for 80%	Power 80% [W]	Total Power 95%+80% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.241	15	HS-DSCH	8	9.2	16	HS-DSCH	11	15.98909
2	DCH	1.552	15	HS-DSCH	8	9.6	17	HS-DSCH	11	13.16545
3	DCH	1.995	15	HS-DSCH	8	10	18	HS-DSCH	11	9.139091
4	DCH	2.742	15	HS-DSCH	8	11	19	HS-DSCH	11	2.345455
5	DCH	3.164	15	HS-DSCH	8	11	20	HS-DSCH	11	-1.49
6	DCH	3.701	15	HS-DSCH	8	12	21	HS-DSCH	11	-6.37364
7	DCH	4.446	15	HS-DSCH	8	12	22	HS-DSCH	11	-13.1464
8	DCH	5.648	15	HS-DSCH	8	14	23	HS-DSCH	11	-24.07

In Figure 6.22 and Table 6.13 it is shown the power required for coverage using FACH for 60% plus DCH for 80% of cell radius and FACH for 80% of cell radius. For example, for two DCH channels at 80% of cell coverage, the transmission power required is 1.344W while FACH power at 60% of cell coverage is 6.4W. Thus, the total power required covering with multiple channels is 7.7W. This power value must be compared with HS-DSCH transmission power at 80% of cell coverage (8W). For this example the power saving obtained is 0.3W which correspond to 3.2%. The results show that from 4 DCHs at 80% plus FACH at 60% of cell onwards is preferable to cover using FACH at 80%. As shown in Table 6.13, in this case it is possible a power saving until 5.58%. From the above mentioned threshold (red row in the table) onwards it is always preferable to serve the users with shared channel at the 80% of cell radius.

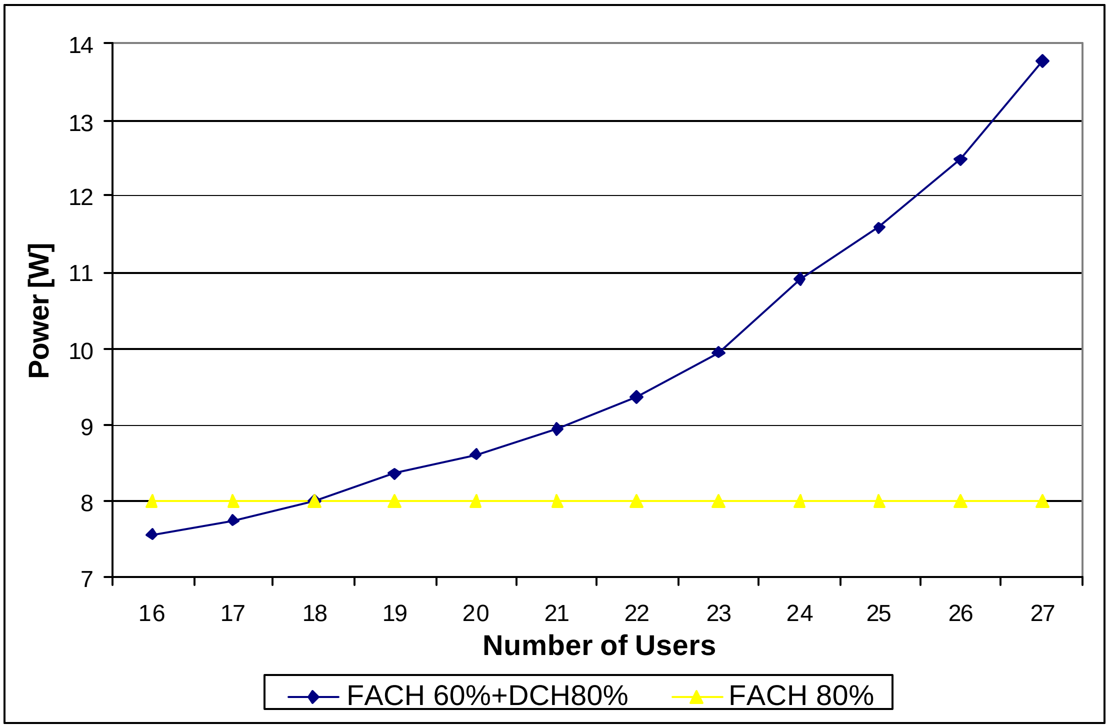

Figure 6.22 : 80%+60% Multiple channels coverage for 128Kbps

Table 6.13: 80%+60% Multiple channels coverage for 128Kbps

Number of UEs at 80%	Channel for 80%	Power 80% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+60% [W]	Total UE	Channel for all UE at 80%	Total power for all UE at 80%	Power Saving %
1	DCH	1.154	15	FACH	6.4	7.6	16	HS-DSCH	8	5.58125
2	DCH	1.344	15	FACH	6.4	7.7	17	HS-DSCH	8	3.1975
3	DCH	1.595	15	FACH	6.4	8	18	HS-DSCH	8	0.05875
4	DCH	1.956	15	FACH	6.4	8.4	19	HS-DSCH	8	-4.44375
5	DCH	2.214	15	FACH	6.4	8.6	20	HS-DSCH	8	-7.6725
6	DCH	2.535	15	FACH	6.4	8.9	21	HS-DSCH	8	-11.6875
7	DCH	2.955	15	FACH	6.4	9.4	22	HS-DSCH	8	-16.9413
8	DCH	3.549	15	FACH	6.4	9.9	23	HS-DSCH	8	-24.3675
9	DCH	4.506	15	FACH	6.4	11	24	HS-DSCH	8	-36.3213
10	DCH	5.186	15	FACH	6.4	12	25	HS-DSCH	8	-44.8188
11	DCH	6.089	15	FACH	6.4	12	26	HS-DSCH	8	-56.1063
12	DCH	7.374	15	FACH	6.4	14	27	HS-DSCH	8	-72.17

In Figure 6.23 and Table 6.14 it is shown the power required for coverage using FACH for 60% plus DCH for 80% and DCH for 95% of cell radius and FACH for 95% of cell radius. For example, for one DCH channel at 95% of cell coverage, the transmission power required is 1.241W and for three DCH channels at 80% of cell coverage, the transmission power required is 1.6W while FACH power at 60% of cell coverage is 6.4W. Thus, the total power required covering with multiple channels is 9.237W. This power value must be compared with HS-DSCH transmission power at 95% of cell coverage (11W). For this example the power saving obtained is 1.763W which correspond to 16.03%. The results show that from 1 DCH at 95% plus 8 DCHs at 80% plus FACH at 60% of cell radius, from 2 DCH at 95% plus 8 DCHs at 80% plus FACH at 60% of cell radius, from 3 DCH at 95% plus 7 DCHs at 80% plus FACH at 60% of cell radius, from 4 DCH at 95% plus 4 DCHs at 80% plus FACH at 60% of cell radius, from 5 DCH at 95% plus 3 DCHs at 80% plus FACH at 60% of cell radius and from 6 DCH at 95% plus 1 DCHs at 80% plus FACH at 60% of cell radius onwards is preferable to cover using HS-DSCH at 95%. As shown in Table 6.14 it is possible a power saving until 20.05%. From the above mentioned thresholds (red rows in the table) onwards it is always preferable to serve the users with shared/common channel at the 95% of cell radius.

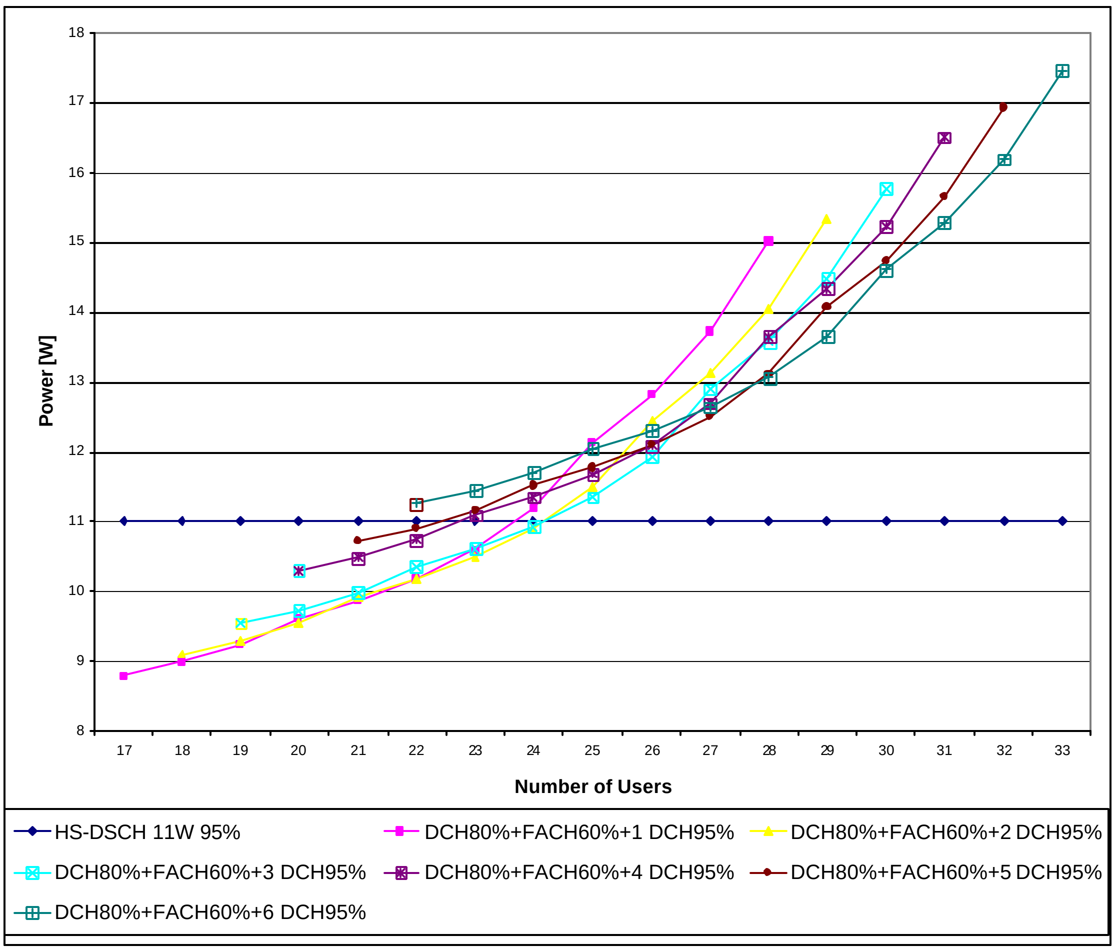

Figure 6.23: 95%+80%+60% Multiple channels coverage for 128Kbps

Table 6. 14: 95%+80%+60% Multiple channels coverage for 128Kbps

Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 80%	Channel for 80%	Power 80% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+80% +60% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.241	1	DCH	1.15	15	FACH	6.4	8.795	17	HS-DSCH	11	20.048182
1	DCH	1.241	2	DCH	1.34	15	FACH	6.4	8.985	18	HS-DSCH	11	18.314545
1	DCH	1.241	3	DCH	1.6	15	FACH	6.4	9.237	19	HS-DSCH	11	16.031818
1	DCH	1.241	4	DCH	1.96	15	FACH	6.4	9.597	20	HS-DSCH	11	12.757273
1	DCH	1.241	5	DCH	2.21	15	FACH	6.4	9.855	21	HS-DSCH	11	10.409091
1	DCH	1.241	6	DCH	2.54	15	FACH	6.4	10.18	22	HS-DSCH	11	7.4890909
1	DCH	1.241	7	DCH	2.96	15	FACH	6.4	10.6	23	HS-DSCH	11	3.6681818
1	DCH	1.241	8	DCH	3.55	15	FACH	6.4	11.19	24	HS-DSCH	11	-1.7327273
1	DCH	1.241	9	DCH	4.51	15	FACH	6.4	12.15	25	HS-DSCH	11	-10.426364
1	DCH	1.241	10	DCH	5.19	15	FACH	6.4	12.83	26	HS-DSCH	11	-16.606364
1	DCH	1.241	11	DCH	6.09	15	FACH	6.4	13.73	27	HS-DSCH	11	-24.815455
1	DCH	1.241	12	DCH	7.37	15	FACH	6.4	15.01	28	HS-DSCH	11	-36.498182
2	DCH	1.552	1	DCH	1.15	15	FACH	6.4	9.105	18	HS-DSCH	11	17.224545
2	DCH	1.552	2	DCH	1.34	15	FACH	6.4	9.296	19	HS-DSCH	11	15.490909
2	DCH	1.552	3	DCH	1.6	15	FACH	6.4	9.547	20	HS-DSCH	11	13.208182
2	DCH	1.552	4	DCH	1.96	15	FACH	6.4	9.907	21	HS-DSCH	11	9.9336364
2	DCH	1.552	5	DCH	2.21	15	FACH	6.4	10.17	22	HS-DSCH	11	7.5854545
2	DCH	1.552	6	DCH	2.54	15	FACH	6.4	10.49	23	HS-DSCH	11	4.6654545
2	DCH	1.552	7	DCH	2.96	15	FACH	6.4	10.91	24	HS-DSCH	11	0.8445455
2	DCH	1.552	8	DCH	3.55	15	FACH	6.4	11.5	25	HS-DSCH	11	-4.5563636
2	DCH	1.552	9	DCH	4.51	15	FACH	6.4	12.46	26	HS-DSCH	11	-13.25
2	DCH	1.552	10	DCH	5.19	15	FACH	6.4	13.14	27	HS-DSCH	11	-19.43
2	DCH	1.552	11	DCH	6.09	15	FACH	6.4	14.04	28	HS-DSCH	11	-27.639091
2	DCH	1.552	12	DCH	7.37	15	FACH	6.4	15.33	29	HS-DSCH	11	-39.321818
3	DCH	1.995	1	DCH	1.15	15	FACH	6.4	9.548	19	HS-DSCH	11	13.198182
3	DCH	1.995	2	DCH	1.34	15	FACH	6.4	9.739	20	HS-DSCH	11	11.464545
3	DCH	1.995	3	DCH	1.6	15	FACH	6.4	9.99	21	HS-DSCH	11	9.1818182
3	DCH	1.995	4	DCH	1.96	15	FACH	6.4	10.35	22	HS-DSCH	11	5.9072727
3	DCH	1.995	5	DCH	2.21	15	FACH	6.4	10.61	23	HS-DSCH	11	3.5590909
3	DCH	1.995	6	DCH	2.54	15	FACH	6.4	10.93	24	HS-DSCH	11	0.6390909
3	DCH	1.995	7	DCH	2.96	15	FACH	6.4	11.35	25	HS-DSCH	11	-3.1818182
3	DCH	1.995	8	DCH	3.55	15	FACH	6.4	11.94	26	HS-DSCH	11	-8.5827273
3	DCH	1.995	9	DCH	4.51	15	FACH	6.4	12.9	27	HS-DSCH	11	-17.276364
3	DCH	1.995	10	DCH	5.19	15	FACH	6.4	13.58	28	HS-DSCH	11	-23.456364
3	DCH	1.995	11	DCH	6.09	15	FACH	6.4	14.48	29	HS-DSCH	11	-31.665455
3	DCH	1.995	12	DCH	7.37	15	FACH	6.4	15.77	30	HS-DSCH	11	-43.348182
4	DCH	2.742	1	DCH	1.15	15	FACH	6.4	10.3	20	HS-DSCH	11	6.4045455
4	DCH	2.742	2	DCH	1.34	15	FACH	6.4	10.49	21	HS-DSCH	11	4.6709091
4	DCH	2.742	3	DCH	1.6	15	FACH	6.4	10.74	22	HS-DSCH	11	2.3881818
4	DCH	2.742	4	DCH	1.96	15	FACH	6.4	11.1	23	HS-DSCH	11	-0.8863636
4	DCH	2.742	5	DCH	2.21	15	FACH	6.4	11.36	24	HS-DSCH	11	-3.2345455
4	DCH	2.742	6	DCH	2.54	15	FACH	6.4	11.68	25	HS-DSCH	11	-6.1545455
4	DCH	2.742	7	DCH	2.96	15	FACH	6.4	12.1	26	HS-DSCH	11	-9.9754545
4	DCH	2.742	8	DCH	3.55	15	FACH	6.4	12.69	27	HS-DSCH	11	-15.376364
4	DCH	2.742	9	DCH	4.51	15	FACH	6.4	13.65	28	HS-DSCH	11	-24.07

4	DCH	2.742	10	DCH	5.19	15	FACH	6.4	14.33	29	HS-DSCH	11	-30.25
4	DCH	2.742	11	DCH	6.09	15	FACH	6.4	15.23	30	HS-DSCH	11	-38.459091
4	DCH	2.742	12	DCH	7.37	15	FACH	6.4	16.52	31	HS-DSCH	11	-50.141818
5	DCH	3.164	1	DCH	1.15	15	FACH	6.4	10.72	21	HS-DSCH	11	2.5690909
5	DCH	3.164	2	DCH	1.34	15	FACH	6.4	10.91	22	HS-DSCH	11	0.8354545
5	DCH	3.164	3	DCH	1.6	15	FACH	6.4	11.16	23	HS-DSCH	11	-1.4472727
5	DCH	3.164	4	DCH	1.96	15	FACH	6.4	11.52	24	HS-DSCH	11	-4.7218182
5	DCH	3.164	5	DCH	2.21	15	FACH	6.4	11.78	25	HS-DSCH	11	-7.07
5	DCH	3.164	6	DCH	2.54	15	FACH	6.4	12.1	26	HS-DSCH	11	-9.99
5	DCH	3.164	7	DCH	2.96	15	FACH	6.4	12.52	27	HS-DSCH	11	-13.810909
5	DCH	3.164	8	DCH	3.55	15	FACH	6.4	13.11	28	HS-DSCH	11	-19.211818
5	DCH	3.164	9	DCH	4.51	15	FACH	6.4	14.07	29	HS-DSCH	11	-27.905455
5	DCH	3.164	10	DCH	5.19	15	FACH	6.4	14.75	30	HS-DSCH	11	-34.085455
5	DCH	3.164	11	DCH	6.09	15	FACH	6.4	15.65	31	HS-DSCH	11	-42.294545
5	DCH	3.164	12	DCH	7.37	15	FACH	6.4	16.94	32	HS-DSCH	11	-53.977273
6	DCH	3.701	1	DCH	1.15	15	FACH	6.4	11.25	22	HS-DSCH	11	-2.3145455
6	DCH	3.701	2	DCH	1.34	15	FACH	6.4	11.45	23	HS-DSCH	11	-4.0481818
6	DCH	3.701	3	DCH	1.6	15	FACH	6.4	11.7	24	HS-DSCH	11	-6.3309091
6	DCH	3.701	4	DCH	1.96	15	FACH	6.4	12.06	25	HS-DSCH	11	-9.6054545
6	DCH	3.701	5	DCH	2.21	15	FACH	6.4	12.31	26	HS-DSCH	11	-11.953636
6	DCH	3.701	6	DCH	2.54	15	FACH	6.4	12.64	27	HS-DSCH	11	-14.873636
6	DCH	3.701	7	DCH	2.96	15	FACH	6.4	13.06	28	HS-DSCH	11	-18.694545
6	DCH	3.701	8	DCH	3.55	15	FACH	6.4	13.65	29	HS-DSCH	11	-24.095455
6	DCH	3.701	9	DCH	4.51	15	FACH	6.4	14.61	30	HS-DSCH	11	-32.789091
6	DCH	3.701	10	DCH	5.19	15	FACH	6.4	15.29	31	HS-DSCH	11	-38.969091
6	DCH	3.701	11	DCH	6.09	15	FACH	6.4	16.19	32	HS-DSCH	11	-47.178182
6	DCH	3.701	12	DCH	7.37	15	FACH	6.4	17.47	33	HS-DSCH	11	-58.860909

6.7.3 Coverage by Multiple Channels for 256Kbps

In this paragraph is depicted only the figure for coverage using DCH at 95% plus HS-DSCH at 60%, DCH at 95% plus DCH at 80% and HS-DSCH at 95% of cell radius for 256Kbps because in the other case the coverage by multiple channels is never convenient.

In Figure 6.24 and Table 6.15 it is shown the power required for coverage using HS-DSCH for 60% plus DCH for 95% of cell radius, HS-DSCH for 80% plus DCH for 95% of cell radius and HS-DSCH for 95% of cell radius. For example, for two DCH channels at 95% of cell coverage, the transmission power required is 2.276W while HS-DSCH power at 80% of cell coverage is 8W. Thus, the total power required covering with multiple channels is 10.276W. This power value must be compared with HS-DSCH transmission power at 95% of cell coverage (11W). For this example the power saving obtained is 0.724W which correspond to 6.59%. The results show that from 2DCHs at 95% plus HS-DSCH at 60% of cell radius and that from 3 DCHs at 95% plus HS-DSCH at 80 of cell radius onwards is preferable to cover using HS-DSCH at 95%. As shown in Table 6.15 it is possible a power saving until 13.79% in case of DCH at 95% plus HS-DSCH at 80% of cell radius and until 4.71% in case of DCH at 95% plus HS-DSCH at 60% of cell radius. From the above mentioned thresholds (red rows in the table) onwards it is always preferable to serve the users with shared channel at the 95% of cell radius.

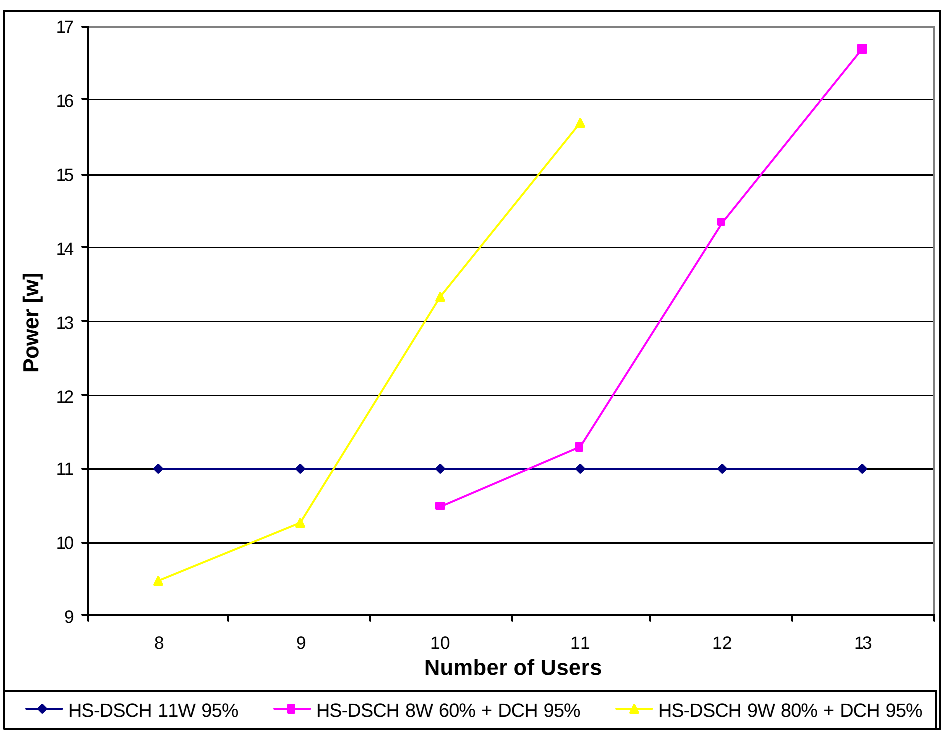

Figure 6.24: 95%+80% and 95%+60% Multiple channels coverage for 256Kbps

Table 6. 15: 95%+80% and 95%+60% Multiple channels coverage for 256Kbps

Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+60% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.482	9	HS-DSCH	9	10.4823	10	HS-DSCH	11	4.7064
2	DCH	2.276	9	HS-DSCH	9	11.2756	11	HS-DSCH	11	-2.505
3	DCH	5.333	9	HS-DSCH	9	14.3329	12	HS-DSCH	11	-30.3
4	DCH	7.688	9	HS-DSCH	9	16.6877	13	HS-DSCH	11	-51.71
Number of UEs at 95%	**Channel for 95%**	**Power 95% [W]**	**Number of UEs at 80%**	**Channel for 80%**	**Power 80% [W]**	**Total Power 95%+80% [W]**	**Total UE**	**Channel for all UE at 95%**	**Total power for all UE at 95%**	**Power Saving %**
1	DCH	1.482	7	HS-DSCH	8	9.4823	8	HS-DSCH	11	13.797
2	DCH	2.276	7	HS-DSCH	8	10.2756	9	HS-DSCH	11	6.5855
3	DCH	5.333	7	HS-DSCH	8	13.3329	10	HS-DSCH	11	-21.21
4	DCH	7.688	7	HS-DSCH	8	15.6877	11	HS-DSCH	11	-42.62

In case of coverage using DCH at 80% and HS-DSCH at 60% is always preferable to serve the users using HS-DSCH at 80% of cell radius.

Table 6. 16: 80% +60% Multiple channels coverage for 256Kbps

Number of UEs at 80%	Channel for 80%	Power 80% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+60% [W]	Total UE	Channel for all UE at 80%	Total power for all UE at 80%	Power Saving %
1	DCH	1.307	15	HS-DSCH	9	10.3069	16	HS-DSCH	10	-3.069
2	DCH	1.773	15	HS-DSCH	9	10.7731	17	HS-DSCH	10	-7.731
3	DCH	2.872	15	HS-DSCH	9	11.8721	18	HS-DSCH	10	-18.72
4	DCH	3.956	15	HS-DSCH	9	12.9559	19	HS-DSCH	10	-29.56
5	DCH	5.052	15	HS-DSCH	9	14.0519	20	HS-DSCH	10	-40.52
6	DCH	6.637	15	HS-DSCH	9	15.6365	21	HS-DSCH	10	-56.37

In case of coverage using DCH at 95% plus DCH at 80% and HS-DSCH at 60% is always better to serve the users using HS-DSCH at 95% of cell radius.

Table 6.17: 95%+80% +60% Multiple channels coverage for 256Kbps

Number of UEs at 95%	Channel for 95%	Power 95% [W]	Number of UEs at 80%	Channel for 80%	Power 80% [W]	Number of UEs at 60%	Channel for 60%	Power 60% [W]	Total Power 95%+80% +60% [W]	Total UE	Channel for all UE at 95%	Total power for all UE at 95%	Power Saving %
1	DCH	1.482	1	DCH	1.3069	9	HS-DSCH	9	11.789	11	HS-DSCH	11	-7.1745

References

[1] 3GPP TR 25.346 V7.7.0 Technical Specification Group Access Network; Introduction of the Multimedia Broadcast Service (MBMS) in the Radio Access Network (RAN) Stage2, (Release7);

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Chapter 7
Conclusions

In this project the importance of the transport channel selection, when delivering Multimedia Broadcast/Multicast Services (MBMS) data in the downlink, for the efficient optimization of UMTS networks in terms of power consumption, has been analyzed. This selection depends on the number of users that must be served, so in order to minimize the power allocated, number of users thresholds to choose the cheapest channel in terms of power consumption have been evaluated. Moreover, the performance improvements in MBMS power resources and capacity, emerging from the employment of HS-DSCH for the MBMS multicast transmission have been investigated. Using DCH, FACH and HS-DSCH all the possible power levels have been considered as well as the option to cover using multiple channels for different percentage of cell radius. A model with 19 hexagonal cells has been implemented to simulate interference by the neighbouring cells, thus for each user the interference from each cell has been calculated, as well as the intra-cell interference, the interference made by the other channels transmitted by the same Node B.

The results revealed that all these transport channels could efficiently be used to deliver the MBMS services, depending on the number of users that desire the service and their requirements. More specifically, through a comparison between the channels power, it is revealed that HS-DSCH can significantly reduce power consumption during MBMS transmission and thus bring more capacity in MBMS enabled UMTS networks.

Three data bit rate have been considered: 64 Kbps, 128 Kbps and 256 Kbps. The cell radius is 0.577 Km and the chosen values of cell radius used in the simulations are 0.550 Km for 95% of cell radius, 0.460 Km for 80% of cell radius and 0.350Km for 60% of cell radius that

correspond respectively to 91%, 64% and 37% of cell coverage considering a typical macrocell environment. The simulations are made by MATLAB and for each channel it has been calculated the transmission power. For each simulation, users have been considered uniformed distributed at the cell border that corresponds to the worst case. To calculate the power of HS-DSCH, Signal to Interference plus Noise Ratio and number of users that must be served have been considered. Of course, for a fixed transmission power, the number of users that HS-DSCH can serve decrease increasing the data bit rate. For each bit rate, it has been calculated the number of users that HS-DSCH can serve.
For data rate of 256Kbps FACH is not used because the needed power will be prohibitive (above 20W) while the three channels have been evaluated for 64Kbps and 128Kbps. Of course the transmission power needed increase with the bit rate for all of them.

For data rate of 64Kbps HS-DSCH is used only for 95% of cell radius since for 80% and 60% cell radius it is cheaper to use FACH. For 95% cell radius and 64Kbps, DCH is used until 10 users and two HS-DSCH transmission power levels have been considered, in this way, until 15 users, it is possible to use 6W, whereas if the number of users is more than 15, 7W must be used and only if the are more than 22 users FACH is preferable. For 80% cell radius and 64Kbps of data bit rate, DCH is used until 17 users than FACH is preferable. For 60% cell radius and 64Kbps of data bit rate, DCH is used until 19 users than FACH is preferable.

For data rate of 128Kbps HS-DSCH is only used for 80% and 95% of cell radius. For the 95% cell radius, three HS-DSCH transmission power levels are used. In this case DCH is used until 8 users, above this number and until 11, HS-DSCH with 7W of transmission power is used, above 11 users and until 15, HS-DSCH with 9W of transmission power is used. The last HS-DSCH transmission power level used is 11W from 16 to 37 users and only when the number of users is greater than 37 FACH is used. For 80% cell radius and 128Kbps of data bit rate, DCH is used until 12 users, than HS-DSCH with 8W of transmission power is used until 15 users and above 15 users FACH is preferable. For 60% cell radius and 128Kbps of data bit rate, DCH is used until 14 users than FACH is preferable.

For data rate of 256Kbps for few users HS-DSCH is cheaper than DCH, for 95% cell radius only until 4 users DCH is preferable. Above that number always HS-DSCH is better. In fact in this case, HS-DSCH with 9W of transmission power is used from 5 to 7 users and HS-DSCH with 11W of transmission power is used from 8 to 18 users. For 80% cell radius and 256Kbps data bit rate, DCH is used until 6 users. Above that number HS-DSCH with 8W of transmission power is used for 7 users and HS-DSCH with 10W of transmission power is used from 8 to 10 users. For 60% cell radius and 256Kbps of data bit rate, DCH is used until 8 users than until 18 users HS-DSCH with 9W of transmission power is used. In each case increasing the number of users always HS-DSCH is the best choice.

The thresholds have been compared also in function of the bit rate for the same percentage of cell radius. For 60% and 80% cell radius each time that the bit rate increase the thresholds decrease in 5 or 6 users. For 95% cell radius thresholds decrease in 2 users for 64Kbps to 128Kbps and 5 users from 128Kbps to 256Kbps.

If users are not uniformed distributed, using one common channel which cover until the furthest user is not always the best choice. For this reason coverage by multiple channels has been considered. Each case considers a different combination of percentage of cell radius and the sum of the transmission power of the multiple channels has been compared to the common channel at the greater percentage of coverage. For each case a threshold to switch to the common channel at the greater percentage of coverage has been evaluated. Using the thresholds found it is possible to use until 41.13% less of transmission power for 64Kbps data bit rate, using a FACH for 60% of cell radius plus one DCH at 95% (this means that just one users is at 95% of cell radius) instead to cover using FACH for 95% cell radius. For 128 Kbps data bit rate it is possible to use until 30.53% less of transmission power, using a FACH for 60% of cell radius plus one DCH at 95% (this means that just one users is at 95% of cell radius) instead to cover using FACH for 95% cell radius. . For 256 Kbps data bit rate it is possible to use until 13.79% less of transmission power, using a HS-DSCH for 80% of cell radius plus one DCH at 95% (this means that just one users is at 95% of cell radius) instead to cover using HS-DSCH for 95% cell radius.

It is expected that all these thresholds can help the network operators in the selection of the most suitable transport channel to deliver MBMS service.

Chapter 8

Future Works

In this project switching thresholds from DCH to HS-DSCH and FACH have been evaluated. For each transport channel it has been calculated the transmission power for different percentage of coverage. The Okumura-Hata model has been considered which is the most used in macrocell environment. The simulations have been made for 64Kbps, 128 Kbps and 256 Kbps data bit rate and for three different percentage of cell radius. The simulations have been made for a BLER target of 1%. It has also evaluated coverage by multiple channels.

The steps that follow this work could be:

- to obtain these thresholds for other values of BLER, for example to repeat these simulation for 5% and 10% of BLER;
- to consider other data bit rates for the MBMS service;
- to examine the power gain using Macro-diversity, this means to evaluate the transmission power gain that is possible to obtain by receiving the signal form more than one cell at the same time;
- to examine the power gain through Multiple Input Multiple Output (MIMO) structures, this means to evaluate the transmission power gain that is possible to obtain using multiple receive antennas which can be used to create parallel virtual orthogonal channels form the Node B to the UE;
- to determinate, once will have examined the techniques at the previous point, the most suitable technique, or the most suitable combination for the transmission of MBMS of service;
- to evaluate the signalling cost for each transport channel, this means to analyze the control messages needed to manage each of this transport channels from a power point of view.

Annex 1

DCH Transmission Power

DCH Transmission Power
The MATLAB code which implements the formula to calculate the DCH's transmission power is the follows.

```
function PT=BSPtDCH(Pp , UsersRb, UsersCoordinate, NeigCellsPw, W, Pn, p,
EbNoRatio)

%It calculates the BS Tx power to cover N users using DCH
%Pp = common control channels power, UsersRB = Rate users vector,
%UsersCoordiante = users' coordinate, NeigCellsPw= neighboring cells power
%W= bandwith Pn=termal noise, p= orthogonality factor

%controls
for k=1:length(UsersCoordinate(1,:))
    if ((UsersCoordinate(1,k)>0.577)||((UsersCoordinate(2,k)>0.577)))
    'user' distance excessive';
    return
    end
end

if (length(UsersCoordinate(1,:)) ~= length(UsersRb))
'Number of Users different to number of BitRate';
    return
end

if (18 ~= length(NeigCellsPw))
'Not valid number of cells';
    return
end

if (length(UsersCoordinate(1,:)) ~= length(EbNoRatio))
'Number of users different to number of EbNoRatio';
    return
end


% power calculating

Numeratore = Pp;
Den=0;

for i=1:length(UsersCoordinate(1,:))

    N1=Pn+ xiCalc(NeigCellsPw, UsersCoordinate(:,i));
    Lp=PathLoss(Distance(UsersCoordinate(:,i),[0;0]));
    D1=(W/(EbNoRatio(i)*UsersRb(i)))+p;
    Numeratore= Numeratore + N1*Lp/D1;
    Den= Den + p/D1;

end
Denominatore= 1 - Den ;

PT = Numeratore/Denominatore;
return;
```

DCH Transmission Power from 1 to N Users

The following code calculates the DCH transmission power to serve from 1 to N users.

```
function PT=DCHTxPwNUsers(Pp , UsersRb, UsersCoordinate, NeigCellsPw, W,
Pn, p, EbNoRatio)

%it determinates the transmission power using of DCH to cover from 1 to N
%users

%controls
for k=1:length(UsersCoordinate(1,:))
    if ((UsersCoordinate(1,k)>0.577)||((UsersCoordinate(2,k)>0.577)))
    'distanza dello utente ecessiva'
    return
    end
end

if (length(UsersCoordinate(1,:)) ~= length(UsersRb))
'Number of Users different to number of BitRate'
    return
end

if (18 ~= length(NeigCellsPw))
'Not valid number of cells';
    return
end

if (length(UsersCoordinate(1,:)) ~= length(EbNoRatio))
'Number of users different to number of EbNoRatio'
    return

%power calculating
for i=1:length(UsersCoordinate(1,:))

    UsRb(i)=UsersRb(i);
    UsCo(:,i)= UsersCoordinate(:,i);
    EbNoR(i)=EbNoRatio(i);

    PT(i)=BSPtDCH(Pp, UsRb, UsCo, NeigCellsPw, W, Pn, p, EbNoR);

end

PTdBm=10*log10(PT*1000);

%result plot
x=1:length(UsersCoordinate(1,:));
plot(x,PT,'-bv');
title('Transmission Power');
xlabel('Number of Users');
ylabel('Power (W)');
legend('DCH Power', 'Location','NorthWest');

save PT PT;

return;
```

InterCell Interference

The MATLAB code which implements the formula to calculate the intercell interference is the follows:

```
function xi=xiCalc(NeigCellsPw, UserCoordinate)

% calculate the intercell interference observed by the ith user using the
% trasmitted power by the neighbouring cells NeigCellsPw and the path loss
% from this user to jth cell. It uses a 18 neighboring cells model

xi=0;

% this matrix models a cellular layout with 18 hexagonal grid cells
CellsCoordinate=[-1.866025404, -1.866025404, -1.866025404, -0866025404, -
0866025404, -0866025404, -0866025404, 0, 0, 0, 0, 0866025404, 0866025404,
0866025404, 0866025404, 1.866025404, 1.866025404, 1.866025404; 1, 0, -1,
1.5, 0.5, -0.5, -1.5, 2, 1, -1, -2, 1.5, 0.5, -0.5, -1.5, 1, 0, -1];

if (length(NeigCellsPw) ~= length(CellsCoordinate(1,:)))
    'Error in intercells interference calculate';
    return;
end

for i=1:(length(NeigCellsPw))

   xi=                                xi                                +
NeigCellsPw(i)/PathLoss(Distance(UserCoordinate,CellsCoordinate(:,i)));

end

return;
```

HS-DSCH SINR

The follow MATLAB code calculate HS-DSCH SINR in function of the power and the distance.

```
function SINRHsdschPw(UserCoordinates, Pn, p, Pown, NeigBSPw, PwHsdsch)
%it calculates the SINRs in function of % of coverage and HS-DSCH power

%calculate
for j=1:length(PwHsdsch)
    for i=1:length(UserCoordinates)
        dBSINR(j,i)=SINRdB(PwHsdsch(j),      UserCoordinates(:,i),      Pn,
NeigBSPw, Pown, p);
    end
end
```

```
%results plot
figure;

for i=1:length(PwHsdsch)
    plot(UserCoordinates(1,:), dBSINR(i,:), color(i)); hold on;

end

save dBSINR dBSINR;

title('Transmission Power Vs SINR');
xlabel('Distance [Km]');
ylabel('SINR [dB]');

return;
```

The follows code calculate the SINR.

```
function dBSINR=SINRdB(hs_dschtxpw, UserCoordinate, Pn, NeigBSPw, Pown, p)
%calculate the SINR in Db

num=0;
den=0;

LpU=PathLoss(Distance(UserCoordinate,[0;0]));

atgain=10^(11.5/10);

num=(hs_dschtxpw*atgain)/LpU;

xi=xiCalc(NeigBSPw, UserCoordinate);

den=Pn+ xi + p*Pown/LpU;

SINR=16*(num/den);

dBSINR=10*log10(SINR);

return;
```

Macrocell Environment

The MATLAB code which implements the macrocell environment is:

```
% this matrix models a cellular layout with 18 hexagonal grid cells
CellsCoordinate=[-1.866025404, -1.866025404, -1.866025404, -0866025404, -
0866025404, -0866025404, -0866025404, 0, 0, 0, 0, 0866025404, 0866025404,
0866025404, 0866025404, 1.866025404, 1.866025404, 1.866025404; 1, 0, -1,
1.5, 0.5, -0.5, -1.5, 2, 1, -1, -2, 1.5, 0.5, -0.5, -1.5, 1, 0, -1];
```

Path Loss

The Matlab code which implements the Okumura Hata's path loss is the follows:

```
function L=PathLoss(R)
%calculate the pathloss from Okumura Hata's model. It uses BS height of
15m
%and frequency of 2 GHz. The distance R has to be in Km


SF=10;

if R >= 0
    LdB=SF+128.1+37.6*log10(R);
else LdB=SF;
end

L=10^(LdB/10);
return;
```

Distance

To calculate the distance it has been implemented the follow code:

```
function D=Distance(A,B)
%it calculates the distance between two point which have the coordinate
[x;y]

D=sqrt((A(1,1)-B(1,1))^2+(A(2,1)-B(2,1))^2);

return
```

Final MATLAB code

64 Kbit/s
For 64 Kbit/s each simulation it has been made using also the follow s function:

```
function PowerDHF(Pp , UsersRb, UsersCoordinate95, NeigCellsPw, W, Pn, p,
EbNoRatio, HsdschPw3, HsdschPw5,HsdschPw6, HsdschPw7, FachPw95, FachPw80,
FachPw60)

%it calculates the DCH, FACH and HS-DSCH Tx power

PT95=0;
PT80=0;
PT60=0;
UsersCoordinate80=0.842105263*UsersCoordinate95;
UsersCoordinate60=0.631578947*UsersCoordinate95;

%controls
for k=1:length(UsersCoordinate95(1,:))
    if ((UsersCoordinate95(1,k)>0.577)||((UsersCoordinate95(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

for k=1:length(UsersCoordinate80(1,:))
    if ((UsersCoordinate80(1,k)>0.577)||((UsersCoordinate80(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

for k=1:length(UsersCoordinate60(1,:))
    if ((UsersCoordinate60(1,k)>0.577)||((UsersCoordinate60(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

if (length(UsersCoordinate95(1,:)) ~= length(UsersRb))
'Number of Users different to number of BitRate'
    return
end

if (18 ~= length(NeigCellsPw))
'Not valid number of cells';
    return
end

if                    ((length(UsersCoordinate95(1,:))                   ~=
length(EbNoRatio))||(length(UsersCoordinate80(1,:))                      ~=
length(EbNoRatio))||(length(UsersCoordinate60(1,:)) ~= length(EbNoRatio)))
'Number of users different to number of EbNoRatio'
    return
```

```
end

%power calculating

for i=1:length(UsersCoordinate95(1,:))

    tic;

    UsRb(i)=UsersRb(i);
    UsCo95(:,i)= UsersCoordinate95(:,i);
    UsCo80(:,i)= UsersCoordinate80(:,i);
    UsCo60(:,i)= UsersCoordinate60(:,i);
    EbNoR(i)=EbNoRatio(i);

    PT95(i)=BSPtDCH(Pp, UsRb, UsCo95, NeigCellsPw, W, Pn, p, EbNoR);
    PT80(i)=BSPtDCH(Pp, UsRb, UsCo80, NeigCellsPw, W, Pn, p, EbNoR);
    PT60(i)=BSPtDCH(Pp, UsRb, UsCo60, NeigCellsPw, W, Pn, p, EbNoR);
    HSDSCH3(i)=HsdschPw3;
    HSDSCH5(i)=HsdschPw5;
    HSDSCH6(i)=HsdschPw6;
    HSDSCH7(i)=HsdschPw7;
    Fach95(i)=FachPw95;
    Fach80(i)=FachPw80;
    Fach60(i)=FachPw60;

    toc;
    residual_time =(length(UsersCoordinate95(1,:))-i)*toc

end

save PT95 PT95;
save PT80 PT80;
save PT60 PT60;

%results plot
x = 1:length(UsersCoordinate95(1,:));
plot(x,PT95,'-v',x,PT80,'-o', x, PT60, '-+', x, HSDSCH3, '-*', x, HSDSCH5,
'-<',x, HSDSCH6, '-s',x, HSDSCH7,'-p', x, Fach95, '-x', x, Fach80, '-^', x
,Fach60, '-d');
title('Transmission Power');
xlabel('Number of Users');
ylabel('Power (W)');
legend('DCH Tx Pw 95% Radius', 'DCH Tx Pw 80% Radius', 'DCH Tx Pw 60%
Radius', 'HS-DSCH3W Tx Pw', 'HS-DSCH 5W Tx Pw','HS-DSCH 6W Tx PW','HS-DSCH
7W Tx Pw', 'FACH Tx Pw 95% Radius', 'FACH Tx Pw 80% Radius', 'FACH Tx Pw
60% Radius', 'Location','NorthWest');

return;
```

128 Kbit/s

For 128 Kbit/s each simulation it has been made using also the follows function:

```
function PowerDHF(Pp, UsersRb, UsersCoordinate95, NeigCellsPw, W, Pn, p,
EbNoRatio, HsdschPw4, HsdschPw5, HsdschPw6, HsdschPw7, HsdschPw8,
HsdschPw9, HsdschPw11, FachPw95, FachPw80, FachPw60)

%it calculates the DCH, FACH and HS-DSCH Tx power

PT95=0;
PT80=0;
PT60=0;
UsersCoordinate80=0.842105263*UsersCoordinate95;
UsersCoordinate60=0.631578947*UsersCoordinate95;

%controls
for k=1:length(UsersCoordinate95(1,:))
    if ((UsersCoordinate95(1,k)>0.577)||((UsersCoordinate95(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

for k=1:length(UsersCoordinate80(1,:))
    if ((UsersCoordinate80(1,k)>0.577)||((UsersCoordinate80(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

for k=1:length(UsersCoordinate60(1,:))
    if ((UsersCoordinate60(1,k)>0.577)||((UsersCoordinate60(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

if (length(UsersCoordinate95(1,:)) ~= length(UsersRb))
'Number of Users different to number of BitRate'
    return
end

if (18 ~= length(NeigCellsPw))
'Not valid number of cells';
    return
end

if                    ((length(UsersCoordinate95(1,:))                   ~=
length(EbNoRatio))||(length(UsersCoordinate80(1,:))                      ~=
length(EbNoRatio))||(length(UsersCoordinate60(1,:)) ~= length(EbNoRatio)))
'Number of users different to number of EbNoRatio'
    return
end


%power calculating
```

```
for i=1:length(UsersCoordinate95(1,:))

    tic;

    UsRb(i)=UsersRb(i);
    UsCo95(:,i)= UsersCoordinate95(:,i);
    UsCo80(:,i)= UsersCoordinate80(:,i);
    UsCo60(:,i)= UsersCoordinate60(:,i);
    EbNoR(i)=EbNoRatio(i);

    PT95(i)=BSPtDCH(Pp, UsRb, UsCo95, NeigCellsPw, W, Pn, p, EbNoR);
    PT80(i)=BSPtDCH(Pp, UsRb, UsCo80, NeigCellsPw, W, Pn, p, EbNoR);
    PT60(i)=BSPtDCH(Pp, UsRb, UsCo60, NeigCellsPw, W, Pn, p, EbNoR);
    HSDSCH4(i)=HsdschPw4;
    HSDSCH5(i)=HsdschPw5;
    HSDSCH6(i)=HsdschPw6;
    HSDSCH7(i)=HsdschPw7;
    HSDSCH8(i)=HsdschPw8;
    HSDSCH9(i)=HsdschPw9;
    HSDSCH11(i)=HsdschPw11;
    Fach95(i)=FachPw95;
    Fach80(i)=FachPw80;
    Fach60(i)=FachPw60;

    toc;
    residual_time =(length(UsersCoordinate95(1,:))-i)*toc

end

save PT95 PT95;
save PT80 PT80;
save PT60 PT60;

%results plot
x = 1:length(UsersCoordinate95(1,:));
plot(x, PT95, '-v', x, PT80, '-o', x, PT60, '-+', x, HSDSCH4, '-*', x,
HSDSCH5, '-<', x, HSDSCH6, '-s', x, HSDSCH7, '-p', x, HSDSCH8, '->', x,
HSDSCH9, '-h', x, HSDSCH11, '--', x, Fach95, '-x', x, Fach80, '-^', x ,
Fach60, '-d');
title('Transmission Power');
xlabel('Number of Users');
ylabel('Power (W)');
legend('DCH Tx Pw 95% Radius', 'DCH Tx Pw 80% Radius', 'DCH Tx Pw 60%
Radius', 'HS-DSCH4W Tx Pw', 'HS-DSCH 5W Tx Pw','HS-DSCH 6W Tx PW','HS-DSCH
7W Tx Pw', 'HS-DSCH 8W Tx Pw', 'HS-DSCH 9W Tx Pw', 'HS-DSCH 11W Tx Pw',
'FACH Tx Pw 95% Radius', 'FACH Tx Pw 80% Radius', 'FACH Tx Pw 60% Radius',
'Location','NorthWest');

return;
```

256 Kbit/s

For 256 Kbit/s, each simulation it has been made using also the follows function:

```
function PowerDH(Pp , UsersRb, UsersCoordinate95, NeigCellsPw, W, Pn, p,
EbNoRatio, HsdschPw95, HsdschPw60)

%it calculates the DCH, FACH and HS-DSCH Tx power

PT95=0;
PT80=0;
PT60=0;
UsersCoordinate80=0.842105263*UsersCoordinate95;
UsersCoordinate60=0.631578947*UsersCoordinate95;

%controls
for k=1:length(UsersCoordinate95(1,:))
    if ((UsersCoordinate95(1,k)>0.577)||((UsersCoordinate95(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

for k=1:length(UsersCoordinate80(1,:))
    if ((UsersCoordinate80(1,k)>0.577)||((UsersCoordinate80(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

for k=1:length(UsersCoordinate60(1,:))
    if ((UsersCoordinate60(1,k)>0.577)||((UsersCoordinate60(2,k)>0.577)))
    'incorrect user distance'
    return
    end
end

if (length(UsersCoordinate95(1,:)) ~= length(UsersRb))
'Number of Users different to number of BitRate'
    return
end

if (18 ~= length(NeigCellsPw))
'Not valid number of cells';
    return
end

if                    ((length(UsersCoordinate95(1,:))                   ~=
length(EbNoRatio))||(length(UsersCoordinate80(1,:))                      ~=
length(EbNoRatio))||(length(UsersCoordinate60(1,:)) ~= length(EbNoRatio)))
'Number of users different to number of EbNoRatio'
    return
end
```

```
%power calculating

for i=1:length(UsersCoordinate95(1,:))

    tic;

    UsRb(i)=UsersRb(i);
    UsCo95(:,i)= UsersCoordinate95(:,i);
    UsCo80(:,i)= UsersCoordinate80(:,i);
    UsCo60(:,i)= UsersCoordinate60(:,i);
    EbNoR(i)=EbNoRatio(i);

    PT95(i)=BSPtDCH(Pp, UsRb, UsCo95, NeigCellsPw, W, Pn, p, EbNoR);
    PT80(i)=BSPtDCH(Pp, UsRb, UsCo80, NeigCellsPw, W, Pn, p, EbNoR);
    PT60(i)=BSPtDCH(Pp, UsRb, UsCo60, NeigCellsPw, W, Pn, p, EbNoR);
    HSDSCH95(i)=HsdschPw95;
    HSDSCH60(i)=HsdschPw60;

    toc;
    residual_time =(length(UsersCoordinate95(1,:))-i)*toc

end

save PT95 PT95;
save PT80 PT80;
save PT60 PT60;

%results plot
x = 1:length(UsersCoordinate95(1,:));
plot(x,PT95,'-v',x,PT80,'-o',  x,  PT60,  '-+',  x,  HSDSCH95,  '-*',  x,
HSDSCH60, '-<');
title('Transmission Power');
xlabel('Number of Users');
ylabel('Power (W)');
legend('DCH  Tx  Pw  95%  Radius',  'DCH  Tx  Pw  80%  Radius',  'DCH  Tx  Pw  60%
Radius', 'HS-DSCH 7W Tx Pw', 'HS-DSCH 6W Tx Pw’, 'Location','NorthWest');

return;
```